NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

**THE UNIVERSAL FUEL AT SEA:
REPLACING F-76 WITH JP-5**

by

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June 2000

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JP-5 THE POTENTIAL "UNIVERSAL FUEL AT SEA"

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ABSTRACT

This research investigates the feasibility, benefits, impacts and costs of replacing F-76 with JP-5 and adopting JP-5 as the single "universal fuel at sea." Joint Publication 4-03, *Joint Bulk Petroleum Doctrine* states, "Department of Defense components should minimize the number of bulk petroleum products that must be stocked and distributed." DoD currently stores and distributes two fuels, F-76 and JP-5, for shipboard use. As the universal fuel at sea JP-5 would replace F-76. All shipboard systems, including boilers, turbine engines and diesel engines that currently operate with F-76 should operate satisfactorily with JP-5. Adopting JP-5 as the single fuel stocked and distributed for shipboard use would simplify logistics support, maximize flexibility, and enhance the readiness and sustainability of U.S. forces at sea.

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LIST OF ACRONYMS

AO	Replenishment Oiler
AOE	Fast combat support ship
APF	Afloat Prepositioning Force
APS	Afloat Prepositioning Ship
BBL	Barrel, 42 U.S. gallons
BFLRF	Belvoir Fuels and Lubricants and Lubricants Research Facility
CBU	Commodity Business Unit
CJCS	Chairman, Joint Chiefs of Staff
CLF	Combat Logistics Force
CNO	Chief of Naval Operations
CONSOL	Consolidation (oiler replenishment at sea)
CONUS	Continental United States
DCMC	Defense Contract Management Command
DESC	Defense Energy Support Center
DFM	Diesel Fuel Marine
DFR	Defense Fuel Region
DFSC	Defense Fuel Supply Center
DFSP	Defense Fuel Support Point
DoD	Department of Defense
DWT	Deadweight Ton (2240 pounds)
F-76	Military specification diesel fuel marine
FAA	Federal Aviation Administration
FEA	Fuel Exchange Agreement
FISC	Fleet and Industrial Supply Center
FSII	Fuel System Icing Inhibitor
FY	Fiscal Year
JP-5	Military specification kerosene based shipboard jet fuel
JP-8	Military specification kerosene based universal (air and ground) fuel
JPO	Joint Petroleum Office
IMP	Inventory Management Plan
LOGREQ	Logistics Request
NDRF	National Defense Reserve Fleet
MARAD	U.S. Maritime Administration
MCMC	Military Contract Management Command
MGO	Marine Gas Oil
MILSPEC	Military Specification
MPF	Maritime Prepositioning Force
MSC	Military Sealift Command
MTMC	Military Traffic Management Command
NAVPETOFF	Navy Petroleum Office
NAVSEA	Naval Sea Systems Command

NAVSTA	Naval Station
NAVSUP	Naval Supply Systems Command
NATO	North Atlantic Treaty Organization
NFAF	Navy Fleet Auxiliary Force
NSFO	Naval Special Fuel Oil
OPA 90	Oil Pollution Act of 1990
PAT	Process Action Team
RRF	Ready Reserve Force
PWRS	Petroleum War Reserve Stock
UNREP	Underway replenishment
USN	Unites States Navy
VTA	Voluntary Tanker Agreement

I. INTRODUCTION

Central to the U.S. Navy war fighting capability and strategy is the capacity to deploy and to sustain forces whenever and wherever required. This capacity is based on the ability to maintain a continuous and responsive logistics flow delivered to forces at sea in the theater of operations. Fuel has the highest demand of all the materials provided by this logistics flow and is one of the most critical supplies. The wars of the previous century are replete with examples of battles and even wars where a deciding factor was an adequate supply of fuel, or more often a lack of it.

Simplicity, flexibility and interoperability have historically proven important to maintaining continuous responsive fuel support (JP 4-0, p. II-1 and JP 4-03, p I-1). To maximize simplicity, flexibility and interoperability, Joint Publication 4-03, *Joint Bulk Petroleum Doctrine* states, "Department of Defense (DOD) components should minimize the number of bulk petroleum products that must be stocked and distributed, plan to use fuels readily available worldwide, and minimize the military-unique characteristics of DOD fuels." (JP 4-03, pp. I-1 – I-2)

Ideally, all of DOD would use a single fuel and that fuel would be a commercial fuel readily available everywhere. Unfortunately, this ideal is not possible. For safety reasons, military specification JP-5 is the only fuel acceptable for use in Naval aircraft at sea. JP-5 is a military-unique fuel that is only available from refineries that manufacture it under contract for DoD and allied forces. Either more than one fuel must be used or the single fuel used must be military-unique.

While the ideal single fuel is not possible, DoD components have adopted military specification JP-8 as the single fuel stocked and distributed for use in all aircraft, vehicles and equipment ashore. Although JP-8 is military-unique, it is identical (with the exception of additives) to commercial JET A1, the international standard jet fuel used in most commercial aircraft. Forces ashore frequently use commercial jet fuels (whenever aircraft refuel at commercial facilities) and other commercial fuels (diesel in vehicles for example) available worldwide as substitutes for JP-8. DoD forces ashore have successfully implemented the principles and guidance of Joint Publication 4-03.

As discussed above, the Navy has not accepted JP-8 or its commercial substitutes at sea for safety reasons. JP-8 and commercial jet fuels have a minimum ignition flash point of 100° Fahrenheit. To prevent fires aboard ship, the minimum acceptable flashpoint for fuels used at sea is 140° Fahrenheit.

Although JP-8 cannot be used at sea, the Navy could adopt JP-5 as the only bulk fuel stored and distributed by DoD for shipboard use. "All shipboard systems, including boilers, turbine engines and diesel engines should continue to operate satisfactorily, and in some instances, with increased efficiency with JP-5." (Tosh, p. ii) DoD, however, continues to store and distribute two fuels for shipboard use, JP-5 and Diesel Fuel Marine (DFM), military specification F-76. JP-5 is used in aircraft. F-76 is used in ships' equipment including ships' propulsion systems. Both JP-5 and F-76 are military-unique fuels and are not readily available worldwide. There is no substitute for JP-5, but JP-5 is an acceptable substitute for F-76.

Since it is possible for the Navy to adopt JP-5 as the single fuel stored and distributed by DoD for shipboard use but it has not done so, it is natural to ask, "why not?" The question has been studied before, starting as early as 1967 (Tosh, p. iii and Higgins, 22 September 1998), and is one of the most frequently asked questions the Navy Petroleum Office receives from flag officers (Higgins, 7 September 1999). The reasons JP-5 has not been adopted as the single fuel at sea are cost and availability. JP-5 costs approximately five cents more a gallon than F-76. Availability is limited because some refineries can't make JP-5 and some oil companies are not interested in making JP-5.

The question, however, needs further examination. Previous studies have concentrated almost exclusively on technical issues, and the cost and availability of JP-5. Because they have been conducted from a technical point of view, the operational, readiness and logistical benefits have been for the most part understated, overlooked and misunderstood. For example the "Navy Fuel Specification Standardization Study" study conducted by the Belvoir Fuels and Lubricants Research Facility in 1992 reported, "The greatest benefit from such a conversion would be the convenience of handling only one fuel, and eliminating the possibility of fuel contamination." (Tosh) This statement, followed by, "The major penalties would include higher fuel cost, and difficulty in procuring adequate supplies of JP-5 to meet the total U.S. Navy shipboard fuel requirements," (Tosh) didn't present a convincing argument to adopt JP-5 as the single fuel at sea. The actual benefits, however, far exceed what could be called "convenience" and eliminating the possibility of fuel contamination pales in significance to other benefits.

In addition, changes in the past decade favor adopting JP-5 as the single fuel for shipboard use. For example, the 1992 Belvoir study reported the increased fuel cost of replacing F-76 with JP-5 would be approximately $103,000,000 a year based on the five cents per gallon standard price difference between JP-5 and F-76 (Tosh, p. 24). The standard price difference between JP-5 and F-76 in FY 1999 was still cents per gallon, but military downsizing has reduced F-76 consumption. Based on 1999 consumption and the same estimating methodology, the estimated cost in 1999 would have been approximately $36,000,000 (Scheffs, 12 March 2000). The difference in the standard prices of F-76 and JP-5 during FY 2000 is only three cents per gallon.

A. PURPOSE AND RESEARCH QUESTIONS

This research investigates the feasibility, benefits, impacts and costs of adopting JP-5 as the single fuel stocked and distributed by DoD for shipboard use. The primary question addressed by this thesis is, should the Navy adopt JP-5 as the only fuel stocked and distributed by DOD for shipboard use? This issue is, however, very complex. The Energy Plans and Policy Branch for Deputy Chief of Naval Operations, Logistics has contracted with consultants and intends to establish a process action team (PAT) to study the issue. The PAT, will include members from the Defense Energy Support Center (DESC), the Navy Petroleum Office (NAVPETOFF), Naval Sea Systems Command (NAVSEA), Military Sealift Command (MSC), and others. The purpose of this thesis is to offer a starting point for the PAT's research efforts. (Roberts and Strucko)

Secondary research questions for this purpose include the following:

(1) What are the technical and maintenance issues involved with replacing F-76 with JP-5 in shipboard equipment and systems?

(2) Is sufficient JP-5 available at reasonable cost from commercial refineries?

(3) What are the operational and readiness benefits and impacts of replacing F-76 with JP-5?

(4) How would replacing F-76 with JP-5 best be implemented?

(5) What would be the cost of replacing F-76 with JP-5?

B. SCOPE AND LIMITATIONS

1. Scope

Since it is the operational and readiness benefits and impacts of JP-5 as the single fuel at sea that have been generally neglected in previous studies, they will be emphasized in this research. The technical feasibility and maintenance issues involved in replacing F-76 with JP-5 will be addressed by a synopsis of previous studies. Availability of adequate refinery supplies of JP-5 will be examined in some detail. Of course, cost is a very important issue and will also be addressed.

2. Limitations

This thesis is limited to unclassified information. Warship fuel storage capacity, war reserve and peacetime operating stock quantities, as well as the methodologies used to calculate those quantities are classified. This limits some discussions in this thesis to

hypothetical examples. It would be valuable to model these events using real data, but that is left for future classified studies.

Cost will be examined, but a true cost-benefit analysis is beyond our scope. Implementation would occur over a period as long as ten years. The price of fuels depends upon the commercial market and cannot be accurately predicted. Transportation costs depend upon the specific refinery sources used and these cannot be identified until contracts are awarded. Using a single fuel would also result in many small cost savings that are difficult to identify and estimate. For example, the accounting and administrative costs of managing one fuel would likely be less than that of managing two fuels.

The savings from use of a single fuel would be spread out among all the storage activities, ships, laboratories, etc. that currently deal with two fuels. The savings at any individual activity might be negligible, but perhaps as a whole they would be significant. Other potential savings that could offset the higher price of JP-5 are similarly difficult to measure.

In addition to the difficulty of measuring costs, it is impossible to put a price on the benefits. What is the dollar value of improved readiness?

Cost will be addressed throughout this thesis, but an accurate cost estimate is beyond the scope of this research and a cost-benefit analysis is not within our scope.

C. METHODOLOGY

A wide variety of references as well as interviews and correspondence were used in the collection of data for this thesis. DoD and Navy publications were used to ascertain

policy, operational requirements and current logistics methodologies. Previous studies of the issue were reviewed, including the "Navy Fuel Specification Standardization" report prepared by the Belvoir Fuels and Lubricants Research Facility, which examined replacing F-76 with JP-5 in April 1992; studies prepared for the DoD conversion to JP-8 as the single fuel used ashore; and a study for the Federal Aviation Administration (FAA) completed in June 1998, which was considering adopting a high-flash point JP-5 type fuel for use in all commercial airlines.

D. ORGANIZATION OF STUDY

This thesis is divided into six chapters. Chapter II provides background information on Naval petroleum logistics, fuel types, and the single fuel concept. Chapter III is a synopsis of previous research on the technical and maintenance issues involved in replacing F-76 with JP-5. Chapter IV addresses the availability of JP-5, both as the most significant problem and the most significant benefit of replacing F-76 with JP-5. Chapter V addresses the operational and readiness benefits and impacts of replacing F-76 with JP-5. Chapter V also examines the cost of replacing F-76 with JP-5. Chapter VI concludes the thesis with recommendations for DoD and suggests areas for further study.

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II. BACKGROUND

A. INTRODUCTION

This chapter provides the background information necessary to understand the universal-fuel-at-sea concept and to assess its feasibility, benefits and impacts. Specifically, this chapter discusses the types of fuel used by DoD, the organizations with petroleum logistics roles related to this research, and the petroleum logistics supply chain from refinery to warship. This chapter also provides historical background and defines the universal-fuel-at-sea concept as interpreted in this research.

B. TYPES AND PRICES OF FUEL

1. JP-5 (Turbine Fuel, Aviation; Naval Jet Fuel)

JP-5 is a 100% kerosene-blend high-flash point jet fuel used by all U.S. Navy shipboard aircraft. JP-5 differs from other jet fuels because its minimum flash point is 140° F. The specifications for both the international standard commercial jet fuel (JET A1) and the DoD jet fuel used ashore (JP-8) only require a minimum flash point of 100°. Flash point is the temperature at which fuel will produce enough vapor to flash into flames when a spark is introduced. Since temperatures aboard ships and on ships' decks can exceed 100° F, and unlike in buildings and on airfields personnel cannot just evacuate or move away from a fire, all Navy shipboard fuels must have a minimum flash point of 140.

JP-5 is the only fuel approved for shipboard aviation. JP-5 is a unique military fuel without any equivalent or substitute, commercial or military. JP-5 is, however, an acceptable substitute for both F-76, the Navy ships' bunker (propulsion) fuel, and for JP-8, the single fuel stored and distributed by DoD for forces ashore. This research examines replacing F-76 with JP-5 and adopting JP-5 as the only fuel routinely stored and distributed by DoD for shipboard use.

2. F-76 (Naval Distillate Fuel)

Naval distillate fuel, commonly referred to as F-76, Diesel Fuel Marine or DFM, is the primary bunker (propulsion) fuel for Navy ships. F-76 is the bunker fuel stored in DoD fuel terminals (DFSPs) and delivered to ships by MSC tankers and Navy oilers. F-76 is similar, but not identical, to Marine Gas Oil (MGO) and other commercial diesels.

A primary difference between F-76 and commercial fuels relates to stability requirements. Refineries use both simple distillation and complex chemical processes to refine crude oil into usable fuels. Distillation separates the crude oil into lighter and heavier components using heat. One of the components obtained from distillation, after some purification, is essentially diesel fuel. The specification for F-76 requires that it be made from this straight distillate. Refineries also use complex chemical processes, cracking for example, to break down heavier crude components into diesel fuels; however, to some extent over time these processes reverse and elements of the fuel will revert to something closer to their crude state. F-76 also contains stability additives that are not typically included in commercial fuels. Because DoD stores fuel for extended periods as

war reserve, stability is essential. Straight distillate fuel and stability additives are required for war reserve storage.

Another significant difference between F-76 and commercial marine diesel is that, for shipboard safety, F-76 has a minimum 140° F. flash point specification. Almost all commercial diesel fuels inherently meet this minimum, however, a minimum flash point is not a standard commercial requirement.

Other F-76 specifications relate to fuel quality. For example, there are limits on particulates and water, ash remaining after burning, and corrosiveness. These specifications are intended to ensure that the fuel will not damage ships' engines over long periods of use.

JP-5, Marine Gas Oil (MGO) and commercial diesels that meet the MGO purchase description are acceptable substitutes for use as ship's bunker fuel. This research examines replacing F-76 with JP-5. Adopting JP-5 as the universal fuel at sea would not prohibit the use of F-76. F-76 would remain an acceptable bunker fuel and could be used freely whenever advantageous.

3. Marine Gas Oil (MGO)

Navy ships must frequently refuel in ports located worldwide that do not have a Navy base or DFSP. Since F-76 is a military specification fuel, it is not available from commercial vendors. Marine Gas Oil (MGO) is an acceptable commercial substitute bunker fuel that is readily available in large quantities and in almost every port worldwide. MGO is approved for use as an alternative bunker fuel only when F-76 is not available.

While MGO is an acceptable bunker fuel, it is not a complete substitute for F-76. If it were a complete substitute, there wouldn't be a need for the F-76 specification. The Navy maintains a purchase description, similar to a specification, for MGO. This purchase description requires that MGO be pure distillate, but does not require stability additives. A minimum 140° F flash point is also required. Other quality requirements are similar to F-76, but less stringent. The U.S. Coast Guard relies on MGO for much of its bunkering. Coast Guard maintenance personnel believe that continuous and long-term use of MGO results in greater wear and higher maintenance costs then when F-76 is used (Roberts, 17 February 2000).

Because it lacks stability additives, MGO must be consumed within six weeks of receipt. MGO is not acceptable for storage in DFSPs as war reserve or even as peacetime operating stock. In addition, MSC and Navy oilers are not permitted to carry MGO. During peacetime, oilers frequently hold stocks longer than six weeks. Oilers also replenish before using all inventory onboard, so some product remains when additional fuel is loaded. Loading oilers with MGO could result in problems due to deteriorating fuel. During a contingency when fuel stock turnover is high, deterioration would be less of an issue.

Loading MGO onboard an oiler also creates much greater risk than created by a single ship bunkering. DESC tests show that most MGO delivered under their bunker contracts does not actually meet the Navy MGO purchase description for minimum quality requirements (Roberts, 17 February 2000). Despite not meeting the requirements, MSC and Navy ships using MGO have not had in any significant problems. If an oiler loaded

MGO that did create problems, however, that fuel would cause problems for an entire battle group or force. The risk of loading MGO as oiler cargo fuel, using the current bunker contract quality assurance arrangements, is unacceptable.

In ports that are frequently visited by Navy ships and where demand will be high enough (10,000 barrels a year), DESC establishes bunker contracts with commercial suppliers. Where DoD supplied fuel is not available and a MGO bunker contract has not been established, ships may procure commercial bunker fuel on an emergency basis. Bunker contracts are established for much smaller order quantities than an oiler would typically require and there is no established procedure for loading oilers with MGO from commercial sources. Adopting JP-5 as the universal fuel at sea would not change the use of MGO as a substitute bunker fuel when military specification fuel is not available. (NAVPETOFFINST 4290.1A)

4. JP-8 (Turbine Fuel, Aviation; The Single Fuel on the Battlefield)

JP-8 is a kerosene-based jet fuel similar to JET A1, the commercial industry-standard jet fuel available worldwide. JET A1 becomes JP-8 with the addition of three mandatory additives: Fuel System Icing Inhibitor, Corrosion Inhibitor, and Electrical Conductivity Additive. These additives are also required in JP-5 (JP-8 The Single Fuel Forward, p. 87).

In order to reduce the number of types of fuel required for military operations ashore and maximize compatibility with commercial fuel, JP-8 has been designated the single fuel on the battlefield for DoD forces ashore. Almost all Army, Air Force, Marine,

and Navy aircraft, vehicles and equipment ashore operate using JP-8. Older equipment that operates on other fuels will be replaced with equipment that uses JP-8. (DESC website)

Because the minimum flash point requirement is only 100° F, JP-8 is not approved for shipboard use. With the exception of minimum flash point, JP-8 and JP-5 are the same type of fuel. Because JP-8 is essentially the common worldwide jet fuel, however, the commercial availability and refinery production of JP-8 and JP-5 are significantly different. The difference in flash point also results in very subtle differences in the physical and chemical characteristics of JP-8 and JP-5. DoD's testing and experience with JP-8 is examined by this research when indicative of the probable results of adopting JP-5 as the universal fuel at sea.

5. JET A1 and JET A (Commercial Jet Fuel)

JET A1 is the commercial industry standard for aviation fuel, available worldwide. JET A1 is essentially identical to JP-8 except that it may not contain three additives that are mandatory in JP-8. JET A is an industry standard variant of JET A1 used only within the U.S. for domestic flights. The sole difference between JET A1 and JET A is the minimum freeze point requirement. JET A1 specifies a – 47° minimum freeze point. JET A specifies a – 40° minimum freeze point. JET A1 is frequently used as a substitute for JP-8 by DoD forces ashore and was used as the single fuel on the battlefield during Desert Storm. (JP-8 The Single Fuel Forward, p. 6)

Because JET A1 and JET A are essentially identical to JP-8, which is very similar to JP-5, technical testing and use of these commercial fuels in diesel engines is examined by this research when indicative of the probable results of using JP-5.

6. Fuel Costs

The prices DoD pays to refineries for fuel rise and fall with the commercial market. In order to facilitate annual budgeting by the services while fuel prices continuously change, DESC annually sets fixed standard prices that they will charge the services for each fuel type.

DESC operates on a non-profit reimbursable basis. Standard prices are based on estimated fuel costs plus a mark-up to reimburse DESC for its costs. DESC's profits and losses are carried forward into the following years and standard prices are estimated each year to return the retained income balance to zero. Table 1 below provides DESC's FY 2000 standard prices and the average price paid per gallon during FY 1999 for the fuels discussed above.

Fuel	FY 2000 Standard Price	FY 1999 Average Purchase Price
JP-5	$.63	$.496
F-76	$.60	$.465
MGO	$.58	$.497
JP-8	$.62	$.493
JET A1	$.61	$.790

Table 1. FY 2000 DESC Standard Prices for Bulk Fuels and FY 1999 Average Purchase Price per Gallon (NAVPETOFF NOTICE 4265, DESC Fact Book FY 99)

Because DESC standard prices include all the costs of fuel support, including transportation, storage, administrative costs, and all other overhead, over the long-term

they reflect the true price of fuel to the taxpayer. The mark-up on MGO is lower than the other fuels reflecting the lower cost of direct delivery bunker contracts that do not require government storage and distribution. The higher price of JET A1 reflects higher prices for smaller quantities at more expensive overseas locations rather than a more expensive fuel. For the purpose of this research, the differences in price between the fuels are more significant than the prices themselves. Historically, these differences have been a little larger, with JP-5 costing approximately five cents more per gallon than F-76.

C. PETROLEUM LOGISTICS ORGANIZATIONS AND RESPONSIBILITIES

The following paragraphs identify organizations with bulk petroleum responsibilities significant to this thesis research.

1. Defense Energy Support Center (DESC)

The Defense Energy Support Center (DESC) is responsible for supporting all DoD energy needs and is the Integrated Materiel Manager for all DoD petroleum requirements. DESC performs worldwide acquisition and contract administration for all DoD bulk fuel requirements, purchasing more light refined petroleum product than any other single organization or company in the world. DESC also owns, finances, and monitors worldwide DoD bulk fuel inventories, oversees fuel terminal and storage operations worldwide, manages bulk fuel transportation and distribution, and is responsible for bulk fuel quality assurance and surveillance. (DESC Website)

DESC is organized into Commodity Business Units (CBU's), each of which is responsible for a part of the DESC mission. Defense Energy Support Center Region staffs, located worldwide, interface with customers and coordinate support within their geographical areas of responsibility. CBU's with responsibilities related to this research are discussed below:

a. Bulk Fuels CBU

The Bulk Fuels CBU functions include consolidating the petroleum requirements of the services; monitoring worldwide DoD fuel inventories; contracting for bulk fuels; quality assurance and surveillance; and managing worldwide bulk petroleum transportation. Transportation responsibilities include establishing policy, managing the transportation budget, and using MSC tankers to move bulk petroleum from refineries to DFSPs and between DFSPs. (DESC website)

b. Direct Delivery Fuels CBU

The Direct Delivery Fuels CBU provides acquisition and management for the Ship's Bunker Fuel Program and for aircraft refueling at commercial airports. Using these programs, end-user customers order and receive fuel directly from commercial vendors at locations where DoD fuel is not available. The Ships' Bunker Fuel Program provides propulsion fuels for Navy, Coast Guard, MSC, and U.S. government owned and chartered ships at 184 ports in the U.S. and 51 other countries. (DESC website)

c. *Facilities and Distribution CBU*

The Facilities and Distribution CBU manages worldwide fuel terminal operations, fuel inventory accounting, and Fuel Exchange Agreements (FEA's) with allied militaries. In partnership with the Unified Commands and the Military Services, DESC Facilities and Distribution develops the annual Inventory Management Plan (IMP), which establishes war reserve and peacetime operating stock inventory levels.

The Facilities and Distribution CBU's Optimization Division uses managerial accounting techniques, statistical tools, modeling, and other decision support tools to identify new business opportunities, evaluate current systems, improve efficiency, validate mission support capability, etc.

2. Deputy Chief of Naval Operations (Logistics)

The Deputy Chief of Naval Operations (Logistics) (OPNAV N4) ensures the adequacy of support for operating force logistics requirements including logistics review of war plans, integrating Navy logistics within the joint arena, and mobilization and industrial preparedness planning efforts (OPNAVINST 4000.85). The Energy Plans and Policy Branch for Deputy Chief of Naval Operations, Logistics has contracted with consultants and intends to establish a process action team (PAT) to study replacing F-76 with JP-5.

3. Navy Petroleum Office (NAVPETOFF)

The Navy Petroleum Office (NAVPETOFF) oversees all Navy fuel programs maintaining close liaison with DESC as the Navy's representative for all petroleum related issues (NAVPETOFF website). NAVPETOFF provide technical direction for petroleum programs within the Navy including facilities management and storage utilization, technical operations, and quality surveillance. (NAVPETOFF Website)

4. Naval Sea Systems Command (NAVSEA)

"The Naval Sea Systems Command (NAVSEA) is the Navy Department's central activity for designing, engineering, integrating, building and procuring U.S. Naval ships and shipboard weapons and combat systems" (NAVSEA Website). NAVSEA establishes military specifications for Navy bunker fuels. (David Higgins, 7 September 1999)

5. Military Sealift Command (MSC)

The Military Sealift Command (MSC) provides petroleum logistics transportation support at the strategic, operational and tactical levels, not only for the Navy, but also for all of DoD.

a. Sealift Program

MSC's Sealift Program provides all strategic sealift for government requirements. During normal peacetime conditions, the MSC Sealift Program operates approximately eight to ten commercial fuel tankers under long-term charter to DoD.

These common-user (for support of all services) tankers lift bulk fuels from refineries for shipment to DFSPs and transfer fuel between DFSPs as needed. During contingencies, these tankers also deliver fuels to the theater. When requirements exceed the capacity of the long-term charter tankers, such as during contingencies, MSC will charter additional commercial tankers or may activate Ready Reserve Force (RRF) vessels. DESC and MSC work closely to coordinate the strategic movement of fuel, with DESC determining requirements and scheduling and MSC maintaining operational control of the tankers.

b. Navy Fleet Auxiliary Force (NFAF)

MSC's Navy Fleet Auxiliary Force (NFAF) is the backbone of the Navy's operational logistics. The NFAF includes 13 Kaiser Class oilers (TAOs). These oilers are used exclusively for to support Navy requirements and they are fully capable of underway replenishment (UNREP) of combatants. TAOs serve as shuttle oilers, transporting fuel from DFSPs to deployed ships and battle groups, and as station ships, assigned to battle groups as organic oilers. NFAF oilers are crewed by civilian mariners and a small military communications detachment.

c. Prepositioning Program

MSC's Maritime Prepositioning Force includes three prepositioned tankers for support of Navy fuel requirements.

6. Maritime Administration (U.S. Dept. of Transportation)

The U.S. Department of Transportation's Maritime Administration (MARAD) maintains the National Defense Reserve Fleet (NDRF), which includes an inactive (mothball) fleet of 20 tankers that can be activated to during national emergencies. Ten of the NDRF tankers are part of the rapid activation Ready Reserve Force (RRF). Each RRF tanker is maintained in a designated days-to-operationally-ready status of four, five, ten, 20 or 30 days. The RRF is intended to support rapid deployment by meeting the critical surge requirements that might occur before sufficient commercial vessels could be chartered. The RRF includes ten of the twenty NDRF tankers. Five of the RRF ships are Offshore Petroleum Discharge System (OPDS) tankers, which carry an underwater hose system and can deliver fuel to forces ashore from four miles out to sea. Once activated, RRF ships are under the control of MSC. (Keane)

7. Military Traffic Management Command (MTMC)

The U.S. Army's Military Traffic Management Command has contracting authority for pipeline, barge, rail car and truck transportation of bulk fuels. MTMC and DESC maintain a close working relationship to manage shipments.

8. Geographical Unified Commanders

DoD has assigned unified combatant commanders for geographic regions of the world. For example, all DoD activities within the Pacific and Indian Ocean areas are under the operational command of U.S. Commander in Chief, Pacific (USCINCPAC).

Unified commanders have the predominant fuels responsibility within their geographic area. Joint Petroleum Offices (JPOs) are assigned under the geographic unified commanders to manage their fuels responsibilities. (Joint Pub 4-03)

9. Joint Petroleum Offices (JPOs)

Under the direction of the Geographical Unified Commander, the JPOs work with DESC and the service components to coordinate fuel support within their assigned area of responsibility. Joint Petroleum Offices are the functional experts in the fuel requirements and infrastructure capabilities for their assigned region. They coordinate the collection of data for determining war reserves and operating stock requirements, track inventories at DFSPs ensuring that war reserves are maintained, coordinate DFSP replenishment, participate in the preparation of operational and contingency planning, and coordinate fuel support during the execution of exercises and operations in their area.

D. THE PETROLEUM SUPPLY CHAIN

The term supply chain implies that petroleum logistics functions operate in a series of links from the refinery to the warship. To a large degree this is true. These links includes refinery purchase, strategic lift, DFSP storage, shuttle lift, cargo consolidation (CONSOL), station ships, and underway replenishment (UNREP). These links are, however, not fixed. Alternative methods of delivering DoD fuels ensure the system is flexible and sustainable. In addition, fuels can also be obtained from local sources, outside

the main supply chain for DoD owned fuel. Figure one below, graphically depicts the petroleum supply chain.

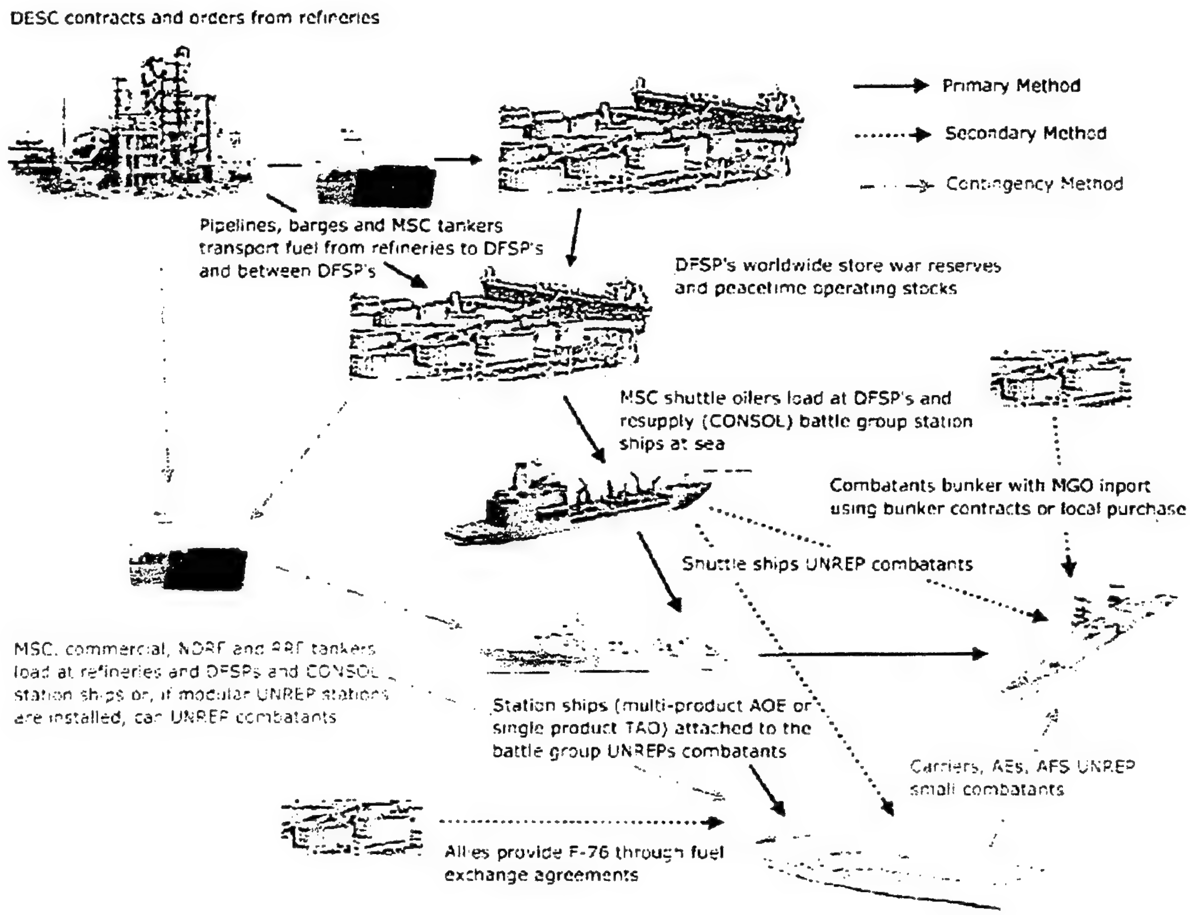

Figure 1. The Petroleum Supply Chain

The end of the petroleum supply chain is UNREP of combatants in the operational area. Delivery to the forces at sea in the area of operations is critical. If ships need to leave the area of operations to transit and receive logistics support 50% of the time, for example, force strength is effectively halved. In this case, delivering logistics support to the theater doubles the strength of the force. While the example above is an unrealistically extreme case, it illustrates the "force multiplier" provided by in theater underway replenishment. The purpose of the petroleum logistics chain is to provide the right fuel, in

the right place, at the right time to enable forces to remain mission capable in the area of operation indefinitely.

1. Acquisition Logistics – Contracting, Ordering and Delivery

a. Determining Requirements

Each year, the Unified Commands, the Military Services, and DESC, through a coordinated effort, promulgate an Inventory Management Plan (IMP) for bulk petroleum. For each DFSP, the IMP sets war reserve and peacetime operating stock inventory levels. Based on the total inventory objectives set by the IMP, inventories on-hand and anticipated demand at each DFSP, DESC estimates and contracts for the quantity of fuels required at each DFSP. When contingencies increase requirements, DESC responds with supplemental contracts for additional fuel. (DESC website)

b. Contracting with Refineries

Bulk fuels are purchased from refinery sources under annual delivery order contracts. Worldwide bulk fuel requirements are divided into four major purchase programs. Western Pacific contracts support U.S. military forces in the Pacific, Indian Ocean, and Middle East areas. Atlantic, Europe and Mediterranean contracts support customers in Europe Iceland and the Azores. Domestic requirements are split into two programs, U.S. East and Gulf Coast contracts (which also support requirements in Panama, Puerto Rico and Guantanamo Bay, Cuba) and U.S. Inland and West Coast contracts (which include Alaska and Hawaii).

Contracts are established through competition among offerors through a negotiation process. Terms and conditions of the contract must be discussed and negotiated with each offeror because each refinery's total capacity, capacity by product type, and commercial customers' demands are different. The price at which each individual refinery can provide fuel will vary depending upon the annual quantity contracted, the size of each order, and other variable factors. These factors must be negotiated to ensure each potential supplier can offer their best price by optimizing their capability. Contracts are not awarded strictly to the lowest bidder. DESC uses a sophisticated linear program that considers the quantities and prices offered by each potential refinery source, demand and constraints at the locations where the fuel will be required, the transportation costs between offering refinery sources and the locations where the fuel will be required, and other costs. Using the linear program and negotiation with offerors, DESC works to award the combination of quantities from each offeror that will result in the lowest total fuel cost, including transportation and all other costs. (DESC website)

Contracts include both requirements and indefinite quantity type contracts. Minimum and maximum annual quantities are defined in the indefinite quantity contracts. Minimum and maximum delivery order quantity limitations are defined in both types of contracts.

c. Ordering

JPOs and DFSPs track their inventory levels and projected requirements. Using the inventory objective and the economic reorder quantities specified in the IMP, these organizations estimate when the reorder point will be reached and request replenishment at that point. In coordination with refineries, MTMC (for surface and barge transport) and MSC (for tanker transport), DESC places a fuel order with a contracted refinery to replenish the DFSP inventory. (DESC website)

Contracts contain price adjustment clauses with prices indexed to commercial market price indicators. As market prices and these corresponding indicators rise or fall, contract prices are adjusted parallel with the commercial market. When fuel is ordered under contract, DESC pays the contract price as adjusted by the contract price index on the date of delivery. (DESC website)

d. Transportation to DFSPs

Most bulk fuel ordered by DESC is purchased free on board (FOB) origin. Origin purchase allows DESC to ship at the lowest cost using the mode best suited to the operation. Pipelines, tankers, barges, trucks and rail cars are used to transport bulk fuels.

About 60% of DESC's domestic shipments are transported by pipeline. The Military Traffic Management Command (MTMC) has transportation contracting authority for all modes except ocean tankers. DESC and MTMC maintain a close working relationship to manage shipping requirements.

Most overseas shipments are made by MSC tanker. The DESC Bulk Fuels CBU manages shipments by ocean tanker. The Military Sealift Command (MSC) charters and retains operational control of ships, responding to DESC's requirements. DESC in coordination with MSC maintains a tanker transportation fleet of eight T-5 equivalent tankers in support of its worldwide tanker resupply mission. This is a core fleet, fully employed during routine peacetime operations. Flexibility, surges and unprogrammed lifts are met by hiring spot charters on an as needed basis.

2. Strategic Logistics – Sealift and Defense Fuel Support Points

On a strategic level, fuel support includes fuel inventories located worldwide at DFSPs and the capability to move fuel to the area of operations with MSC sealift.

a. Defense Fuel Support Points

Defense Fuel Support Points (DFSPs) are fuel terminals that store DESC owned fuel. Table 2 below identifies the DFSPs worldwide that support Navy F-76 and JP-5 requirements. Logically, many of these DFSPs are located on or near naval bases.

Fuel stored is both Petroleum War Reserve Stocks (PWRS) and peacetime operating stocks. PWRS are sized to meet the deployment and combat operation requirements of a contingency in the geographic area until resupply can be obtained from a secure source (DDOD 3110.6). Peacetime operating stock levels are sized to cover average peacetime demand and most variation in demand between routine replenishments. PWRS and peacetime operating stock levels as well as the methodology used to determine them are classified. When demand is higher than expected, even during peacetime,

FISC San Diego (Point Loma), CA	NAS North Island, CA
SUBASE New London, CT (F-76 only)	FISC Jacksonville, FL
NAS Key West, FL (JP-5 only)	NAS Pensacola, FL (JP-5 only)
NAVSUBASE Kings Bay, GA (F-76 only)	FISC Pearl Harbor, HI
DFSP Carteret, TX	DFSP Houston, TX
DFSP Craney Island, VA	DFSP Sewells Point, VA
NAB Little Creek, VA	FISC Puget Sound (Manchester), WA
DFSP Souda Bay, Crete (NATO)	NAVSTA Guantanamo Bay, Cuba
NSF Diego Garcia	COMNAVMARIANAS Guam
DFSP Augusta Bay, Italy (NATO)	DFSP Gaeta, Italy (NATO) (F-76 only)
DFSP Hakozaki, Japan	DFSP Yokose, Japan
DFSP Akasaki, Japan	DFSP Iorizaki, Japan
DFSP Kwajalein, Marshall Islands	NAVSTA Roosevelt Roads, Puerto Rico
DFSP Senoko, Singapore	NAVSTA Rota, Spain
DFSP Aden, Yemen	

Table 2. DFSPs that Support Navy F-76 and JP-5 Fuel Requirements (NAVPETOFF INSTRUCTION 4025.1D)

peacetime operating stocks may be depleted and PWRS used. Peacetime penetrations of PWRS are reported to DESC and the Geographical Unified Commander and replenishment is scheduled as soon as practical.

DESC oversees but does not operate DFSPs. DFSPs may be government owned and operated, government owned and contractor operated, contractor owned and

operated, or may even be owned and operated by an allied foreign government. Many of the DFSPs that support the Navy bunker requirements are owned and operated by the Navy.

At locations where pipelines connect the DFSP to Navy base piers, fuel is delivered from the DFSP by pipeline to the ship or oiler. Where DFSPs are not connected by pipeline to the Navy base piers, fuel is either delivered to the ship by barge or tank truck, or the receiving ship must go to the DFSP's pier. Most DFSPs own the barges and tank trucks used for delivery. Due to the quantities required, oilers must be loaded by pipeline.

During normal peacetime operations and during most contingencies, the nearest DFSP will be the primary source of fuel for Navy operations. To guarantee oilers are loaded only with fuels that meet military specifications, unless specifically arranged, oilers will only load at DFSPs. DFSPs are also the required source for Navy ships' in-port replenishment when at a location supported by a DSFP.

b. Strategic Sealift – Movement to the Theater of Operations

Strategic lift of fuel is accomplished through tanker transportation directly from refineries or from DFSPs outside the area of operations to the theater. For Navy fuel requirements, strategic sealift usually moves fuel to the DFSP nearest to the operations.

Strategic sealift is common-user transportation; that is it supports all services and defense agencies, and is the responsibility of Military Sealift Command (MSC). MSC must apportion strategic sealift capacity to meet joint requirements. When

assets are insufficient to fill all requirements on schedule, the unified commander determines shipment priorities.

The first asset used for strategic sealift is MSC's core fleet, discussed above. During contingencies, MSC will procure additional charter tankers to meet the additional requirements of strategic lift. If possible, U.S. flagged commercial tankers will be chartered, however, strategic fuel lift requirements during contingencies are expected to exceed the capacity of suitable and available U.S. merchant tankers. If a sufficient number of merchant tankers are not available, MSC must use foreign flagged ships or activate RRF and NDRF tankers. (Miller, p. 39)

In addition to moving fuel forward to the DFSP nearest to the operations, tankers can also deliver fuel directly to forces at sea by transferring fuel at sea to oilers and can even provide limited underway replenishment to combatants. These options will be discussed below.

3. Operational Logistics – Shuttle Ships and Cargo Consolidation

The acquisition and strategic logistics links in the supply chain provide fuel to the area of operations, usually to the nearest DFSP. Operational logistics delivers that fuel to forces at sea in the area of operations.

Sustaining multiple battle groups at sea requires a continuous flow of shiploads of fuel. MSC's Kaiser Class Oilers (TAOs) will shuttle fuel from the nearest DFSP to the forces. Ships steaming independently or in a smaller task force are not typically accompanied by an oiler, and receive UNREP directly from these shuttle oilers. For battle

group resupply, shuttle oilers will transfer cargo fuel to the oiler accompanying the battle group and, if time permits, may also directly UNREP combatants. The transfer of cargo fuel to oilers at sea is referred to as cargo consolidation (CONSOL).

In addition to delivering fuel to the DFSP nearest to the operating area, commercial, NDRF, and RRF tankers can bypass the DFSP nearest the theater and directly CONSOL oilers at sea using the receiving oilers UNREP stations. Although this direct delivery capability makes using the nearest DFSP unnecessary, it is not usually advantageous to CONSOL from tankers. Fuel consolidations from merchant tankers can take up to two days operating only in daylight hours (Miller, p. 25).

The larger the force and the further from DFSP storage, the greater the number of oilers required to shuttle consolidation cargos to the deployed force. At some combination of force size and distance the number of oilers will be insufficient and direct tanker CONSOL will become advantageous or even necessary.

Shuttle ships are assigned under the operational control of the logistics task force commander. The logistics task force commander coordinates with the force commander and battle group commanders to develop shuttle schedules. Battle group commanders will be informed when a shuttle will arrive and the time it can remain with the battle group before it should be released to support other forces or replenish. The battle group commander assumes tactical control of shuttle ships while they are operating with the battle group. Effective operational and tactical control is necessary to prioritize delivery to where it is most urgently needed and to where it will not interfere with operations. In addition, since oilers and tankers are defenseless high-value assets, effective operational

and tactical control is necessary to minimize the probability of an encounter with the enemy and to coordinate protective escorts.

4. Tactical Logistics – Station Ships and Underway Replenishment

The tactical end of the petroleum logistics supply chain provides UNREP to combatants where and when desired by operational commanders. Ideally, each battle group includes an organic Combat Logistics Force (CLF) fast combat support ship (AOE) that will continuously remain with the battle group providing storage and distribution of replenishment stocks of petroleum, ammunition, parts and stores.

Organic storage of replenishment stocks is necessary to provide adequate endurance for battle groups. If a shuttle ship is lost to enemy action or mechanical casualty, a station ship would be essential to ensure adequate fuel is on-hand to support operations until another shuttle ship arrives. In addition, fuel consumption by a battle group can have considerable and difficult to predict variance. The fuel economy curve for ships is nonlinear and changes in speed and the intensity of operations greatly impact consumption (Modisette, p. 8). Without the station ships' fuel stocks, shuttle replenishment would be required much more frequently, based on the highest possible consumption rates.

In addition to organic storage and increased endurance, station ships provide flexibility for the operational commander to schedule UNREP when it will not interfere with operations and when it is safe. UNREP ships transfer fuel to other ships while steaming alongside at only 150 feet apart. At times sea state, restricted area, and shallow

water can make underway replenishment impossible. Ships usually must change course and reduce speed to conduct UNREP. During UNREP the combat capability of the ships involved is significantly degraded. In a high-intensity conflict or during inclement weather, the operational commander must have the flexibility to delay UNREP to unsure the safety of both the receiving ship and the CLF ship. To ensure ships' fuel levels remain high enough to delay UNREP when necessary, Battle Group Commander will typically schedule replenishment of each ship in the battle group about every four days. UNREP scheduling is an important operational issue. (Miller, pp. 3-17)

Ships and groups operating without a station ship receive UNREP from shuttle oilers as scheduled by the logistics task group commander.

To ensure the capability to maintain forces at sea despite losses of oilers to enemy action or mechanical casualty, the Navy has developed and produced modular fuel delivery stations that can be rapidly installed on merchant tankers for tanker-to-combatant UNREP. Each modular UNREP station has two hoses and can deliver two different fuels, each at a rate of 3,000 gallons per minute or one fuel at a rate of 6,000 gallons per. One station can be operated without increased tanker manning. Two stations would require an additional eight to ten crewmembers. The UNREP capability of merchant tankers would be significantly less than the capability of MSC and Navy oilers. (Miller, p. 39)

5. Host Nation Support

In addition to DoD owned fuel and the petroleum supply chain discussed above, Navy forces also draw on allied governments and commercial sources for fuel support.

a. Fuel Exchange Agreements

DESC has established agreements with 91 countries to provide fuel to DoD on a reciprocal basis (most of these agreements are for shore-based aircraft support). These bilateral fuel exchange agreements (FEA's) are used as the second level of supply when U.S. Government owned fuel is not available. Many of our allies also use F-76 and JP-5 and are able to provide fuel to visiting ships through FEA's. Table 3 below lists the countries with which we share FEA's that support Navy ships' fuel requirements.

Argentina	MGO
Australia	F-76, JP-5
Canada	F-76, JP-5
Chile	F-76
France	F-76, JP-5
Japan	F-76
Korea	F-76, JP-5
Malaysia	MGO
Pakistan	F-76, JP-5
Peru	F-76, JP-5
Turkey	F-76
United Kingdom	F-76, JP-5

Table 3. Countries Participating in Bilateral Fuel Exchange Agreements (NAVPETOFF INSTRUCTION 4025.1E)

Arrangements to transfer fuel under FEA's vary depending on the agreement and circumstances. Support from some countries is very limited. For large battle group requirements, the area JPO or battle group commander must arrange requirements far in advance. Most often, JP-5 is not available in quantities required by carrier battle groups.

b. Bunker Contracts

Worldwide Bunker fuel contracts provide a third level of supply where U.S. Government owned stocks and FEA's are not available. DESC has contracts for the direct delivery of ships' bunker fuels in 94 CONUS ports and 90 overseas ports in 51 countries. (Ships' Bunkers Purchase Procedures)

The type of fuel Navy ships receive from these contracts is normally Marine Gas Oil (MGO). Contracted suppliers are provided the DoD purchase description for MGO and agree to provide fuel meeting the specification. Ordering officers (ships' supply officers) are responsible for ensuring the fuel delivered meets specifications. (NAVPETOFFINST 4290.1A)

DESC has contracted with a commercial company that provides sampling kits, packaging and sample shipment to the contracted laboratory. MSC vessels take samples for testing whenever fuel is loaded. These tests do not confirm the fuel is on-specification prior to loading, but are used to check contractor compliance. In 1999, DESC spent $100,000 for MGO testing. (DESC website)

c. Open Market Purchase of Bunker Fuel

In ports where there is no DFSP, FEA, or bunker contract, ships' are authorized to make an open market purchase of bunker fuel only if operational considerations prevent delay of fueling until U.S. Government owned or DESC contracted sources for fuel are available. Deployed ships are required, however, to refuel whenever on board inventory is projected to drop below 80% of capacity. This requirement usually

means that, unless an UNREP is scheduled shortly before or after a port visit, ships will refuel during that port visit. For ships steaming independently, not in a task force or battle group, bunkering from non-contract sources is fairly common. The type of fuel Navy ships receive from these purchases is Marine Gas Oil (MGO). The Contracting Officer, normally the ships' supply officers, is responsible for ensuring the fuel delivered meets specifications. (NAVPETOFFINST 4290.1A)

E. HISTORICAL BACKGROUND

1. The Universal Fuel at Sea

In the late 1960's the navy used three fuels to power its ships and aircraft: Navy Special Fuel Oil (NSFO) was used for steam generation; Fuel Oil, Diesel marine was used in diesel engines, small craft and for auxiliary power on some ships; and JP-5 was used for carrier based aircraft. Fuel Oil, Diesel and JP-5 were also acceptable substitutes for use in boilers. (Tosh)

In 1967, the idea of adopting JP-5 as the only fuel used aboard Navy ships and aircraft was first examined. At that time JP-5 cost twice as much as NSFO and it appeared that there would be insufficient supplies of JP-5 to meet both propulsion and aviation requirements. Although JP-5 was not adopted as the only fuel, F-76 was adopted as the fuel used for ship's propulsion, replacing NSFO. (Tosh)

Since that time, interest in converting to a single fuel has continued. Surprisingly, the interest in adopting JP-5 as the ship's propulsion fuel has not generally originated from

supply logisticians. Much of the interest has been based on the potential for reducing turbine engine maintenance.

The most significant study was conducted in 1992 by the Belvoir Fuels and Lubricants Research Facility. That study concluded that conversion "would not be detrimental to fleet operational readiness," but that the benefits are "very difficult to quantify," and that it would be, "at least initially, very costly for the Navy." (Tosh) In summary, the study did not present a strong case for converting to all JP-5.

2. The Single Fuel on the Battlefield

DoD forces ashore have adopted JP-8 as the single fuel on the battlefield (also called the single fuel forward) used to fuel all DoD land based aircraft, vehicles, and equipment. Although improved logistics capability is the most touted benefit of the conversion to a single fuel on the battlefield, it was not the sole impetus for conversion (JP-8 The Single Fuel Forward). In fact, prior to the conversion many petroleum logisticians believed the conversion was not possible due to a limited availability of JP-8 from refineries (Roberts, 17 February 2000).

Conversion to JP-8 from JP-4 for land-based aircraft was initially proposed in 1975. The rational was commercial availability (it is JET A1 plus additives) and increased safety (JP-4 has no minimum flash point). Conversion for of all vehicles and equipment ashore began in 1981 when the M1 Abrams Main Battle Tank and other gas turbine equipment experienced severe cold start problems in Germany using NATO standard diesel. Initially, a jet fuel-diesel mix was used in the winter months, but all NATO ground

equipment was converted to JP-8 by 1992. Conversion of all DoD equipment ashore worldwide, with minor exceptions, is fully implemented today. (JP-8 The Single Fuel Forward)

DoD remains flexible in its single fuel on the battlefield concept. During Operation Just Cause in Panama and the Haiti and Somalia peacekeeping missions, JP-5 was designated the single fuel forward and was used in all Army, Air Force, Navy and Marine Corps vehicles, aircraft, and equipment ashore. (White Paper on JP-8, pp. 10-11). During Desert Storm JET A1 was used as the Single Fuel on the Battlefield (JP-8 The Single Fuel Forward).

F. THE UNIVERSAL-FUEL-AT-SEA CONCEPT DEFINED

The universal-fuel-at-sea concept simply replaces F-76 purchased by DESC and stored in DFSPs as war reserve and peacetime operating stocks with JP-5. Although the concept as defined by this research is simple, it is variously interpreted and sometimes misunderstood. The most frequent misunderstandings encountered while discussing this research with DoD personnel were, that if JP-5 is the universal fuel at sea, F-76 and MGO can never be used and since JP-5 is not available from commercial vendors it will reduce the number of "gas stations" available to the warfighter.

Although JP-5 is a military specification fuel that is not available to the warfighter from commercial vendors, F-76 is also a military specification fuel that is not available to the warfighter from commercial vendors. The universal-fuel-at-sea concept does not mean that F-76 and MGO cannot be used. It does not mean that F-76 supplied by allies under

FEA's or MGO supplied by commercial sources under bunker contracts cannot be used. Adopting a universal fuel at sea does not mean the principles of maximizing flexibility and host nation support would be abandoned.

Just as the Air Force continues to refuel with JET A1 at commercial airports though JP-8 is the single fuel ashore, the Navy would continue to bunker with MGO from in ports without DoD fuel stocks though JP-5 is the universal fuel at sea. JET A1, not JP-8, was the single fuel on the battlefield (ashore) during Desert Storm (JP-8 The Single Fuel Forward). JP-5, not JP-8, was the single fuel on the battlefield (ashore) during Operation Just Cause in Panama and the Haiti and Somalia peacekeeping missions (White Paper on JP-8, pp. 10-11).

G. CHAPTER SUMMARY

This chapter provided background information relevant to replacing F-76 with JP-5 and adopting JP-5 as the universal fuel at sea. Chapter III examines the technical issues relating to using JP-5 in shipboard equipment and the feasibility of replacing F-76 with JP-5.

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III. TECHNICAL FEASIBILITY AND MAINTENANCE IMPACTS

A. INTRODUCTION

Adopting JP-5 as the universal fuel at sea will only be possible if all systems and equipment can operate satisfactorily with JP-5. JP-5 has often been used as a bunker fuel when F-76 was not available, even during contingency operations and for extended periods. JP-5 that no longer meets aviation specifications, but is still suitable for bunker fuel is infrequently but routinely downgraded to F-76. During the Iranian crisis in 1982-83, all ships operating in the Indian Ocean were replenished only with JP-5 because Diego Garcia did not have stocks of F-76 (Tosh, p. 18). From 1980 through 1983, all Army equipment operating in the Panama area out of Fort Clayton ran on JP-5; there were no reported problems (Tosh, p. 21). Today, Naval Air Station Key West only carries JP-5 and supplies JP-5 as bunker fuel to visiting ships.

Although JP-5 has been routinely used as bunker fuel, not all JP-5 specifications match or exceed all F-76 specifications. For example, the maximum cloud point for F-76 is -1˚C, but JP-5 does not have a maximum cloud point requirement. Most specification differences are not significant. In the cloud point example mentioned above, for example, on-specification JP-5 always inherently meets the F-76 cloud point specification. Some differences between JP-5 and F-76 have, however, been identified as potential problems: lower heat value, lower cetane number, and lower viscosity and lubricity.

This chapter discusses these potentially problematic attributes of JP-5 as well as other fuel specification issues. This chapter also specifically addresses the technical and maintenance impacts of using JP-5 in each of three types of systems the Navy uses for propulsion and auxiliary systems: steam-power, gas turbines and diesel engines.

B. PROBLEMATIC ATTRIBUTES OF JP-5

1. Lower Heat Value

Belvoir Fuels and Lubricants Research Facility (BFLRF) tests found that on average JP-5 has 2.6% less volumetric energy content (BTU) than F-76 (Tosh, p. 5). The BFLRF study directly translates this into a 2.6% reduction in range and a 2.6% increase in the amount of fuel purchased. (White Paper on JP-8, p.8)

Real world experience, however, generally does not support this theoretical increase in fuel consumption. JP-8 has an even lower energy density than JP-5; five and one half percent lower than diesel (JP-8 The Single Fuel Forward, p. 19). In real world usage, there has not been an increase in fuel consumption where JP-8 has replaced diesel in fielded vehicles and equipment. During the introduction of JP-8 to NATO, fuel requirements were expected to rise more than four percent based on theoretical consumption; however, there was no increase in demand (JP-8 The Single Fuel Forward, p. 36). A JP-8 demonstration program at Fort Bliss in 1989 found no significant differences in vehicle or equipment fuel consumption rates after switching from diesel to JP-8 (JP-8 The Single Fuel Forward, p. 45). Moreover, since the introduction of JP-8 as

the single fuel on the battlefield, there has been no indication of increased consumption worldwide (Roberts). The Navy has not identified reduced range or increased consumption as an issue or problem when JP-5 has been used as bunker fuel.

2. Lower Cetane Number

Cetane number is measure of the starting and warm-up characteristics of a fuel. The minimum cetane number for F-76 is 45.0. JP-5 does not have a cetane number specification and most samples do not meet the F-76 specification (Tosh, p. 6). Lower cetane numbers can mean cold-starting problems and reduced durability in some diesel engines and slower acceleration and lower maximum power in power-limited systems. Potential problems specific to diesel engines are discussed in paragraph G below.

There is some reduction in acceleration and power in most engines using jet fuel when compared to using diesel fuel. The loss is most noticeable at full throttle and deviation is highly engine and injection system dependent. Engines that use pressure-time metering of fuel show little power effect, while engines with higher injection pressures have greater power deviation. Some engines exhibited increased power after mechanical adjustment. Army testing found that power loss after changing to JP-8 was only significantly noticeable in a few power-limited systems and vehicle operator acceptance of JP-8 was favorable. The Navy has not identified reduced acceleration or maximum power as an issue or problem when JP-5 has been used as bunker fuel. (JP-8 The Single Fuel Forward, p. 129)

3. Lower Lubricity

Lower lubricity can result in greater wear in fuel-lubricated pumps and fuel injectors. The BFLRF study reports that individuals who participated in the Iran crisis operations, during which JP-5 was the only fuel used, recalled a noticeable increase in wear rate problems in fuel pumps and injectors. However, these failures were not documented and failed parts were not inspected. The extent and cause of the problems are speculative. (Tosh, pp. 18-20)

During Desert Storm, use of JET A1 in equipment ashore was initially blamed for excessive wear in rotary-type injection pumps and other fuel-lubricated systems Subsequent investigation determined, however, that some of rotary pump problems resulted from a previously identified part design deficiency and the worn parts were supposed to have been replaced. Most other fuel related problems during Desert Storm were found to be caused by dirt and water contamination, flex-ring failures, unauthorized maintenance practices, improper rebuilds and cumulative wear, rather than JET A1's low lubricity.

General Motors limited warranty provisions on the Commercial Utility Cargo Vehicle because the fuel injection pump manufacturer maintained that severe wear would result from using JP-8 when ambient temperatures were above 71° F. However, two severe 10,000-mile tests conducted at GM's Desert Proving Ground, during the hottest time of the year, found no pump wear whatsoever. (JP-8 The Single Fuel Forward, p. 26)

JET A1 and JP-8 have even lower viscosity than JP-5 and JET A1 does not require the anti-corrosion additive in JP-5. While the examples above are inconclusive and additional wear in some fuel lubricated parts may be expected, the successful adoption of JP-8 and use of JET A1 in all DoD systems ashore indicates that problems using JP-5 should be minor and manageable.

4. Lower Viscosity

The lower viscosity of jet fuels may result in internal leakage from the high-pressure regions of fuel pumps and injection nozzles designed for diesel fuels. In systems that had significant power loss after changing to JP-8, this leakage may have been a larger source of power loss than lower heat content or lower cetane number. During the Haitian peacekeeping mission, where JP-5 was designated the single fuel ashore, contractors operating commercial vehicles with General Motors 6.5L diesel engines and rotary fuel injection pumps had hot starting problems due to low viscosity. The fuel injection pump manufacturer acknowledged a design problem and issued a replacement hydraulic head and rotor. Similar problems have occurred when JP-8 was used in commercial vehicles. Since, fuel viscosity changes with temperature, all systems are designed to accept some changes in fuel viscosity. JP-5 viscosity is higher than JP-8 and nearly the same as some diesel fuels. Robust designs should not be affected. (White Paper on JP-8, p. 11)

C. FUEL SYSTEMS AND STORAGE

1. Fuel System Materials

JP-5 is completely compatible with diesel fuel system materials (e.g. fuel lines, filters, seals, etc.) (JP-8 The Single Fuel Forward, p. 24). Fuel system elastomers and seals are unaffected by the conversion from diesel to jet fuel (White Paper on JP-8, p. 3). Reduced water entrainment and emulsification could reduce fuel system corrosion. (White Paper on JP-8, p. 2)

2. Improved Storage Stability

Using JP-5 will reduce problems related long-term fuel storage and deterioration. Jet fuel is more thermally and oxidatively stable than diesel fuel, reducing the formation of long-term storage deterioration by-productions (White Paper on JP-8). Because JP-5 has stricter water reaction interface and water separation index specifications, it has better water separation qualities and tends to entrain less water than diesel. JP-5 is also more resistance to breakdown by microbiological organisms. Diesel contains more paraffin-type hydrocarbons, which are a favored nutrient of some microorganisms. The Fuel System Icing Inhibitor (FSII) additive in JP-5 also acts as a biostat protecting against microbiological growth. In addition, storing only one fuel will result in easier first-in-first-out inventory turnover.

3. Mixing Fuels

Switching fuels or mixing fuels in bunker tanks does not have technical or maintenance impacts except when JP-5 is added to tanks containing deteriorated or contaminated diesel or MGO. The introduction of the Fuel System Icing Inhibitor in JP-5 into tanks containing excessive water, debris, or deteriorating fuel will gradually kill microbiological organisms and dissolve gums and sediments. This contamination will then be carried into the fuel filters. In other words, adding JP-5 to tanks holding F-76 or MGO will clean the fuel tanks and system and may initially result in more frequent filter changes.

Aircraft-quality cleanliness must maintained in tanks and fuel distribution systems used to support aircraft refueling. JP-5 mixed with F-76 or MGO or stored in water-ballasted tanks cannot be used for aviation. Since F-76 and MGO would still be used as bunker fuels whenever advantageous, segregated storage and fuel systems would still be required. Under the universal fuel concept, to the greatest extent practical, all JP-5 and all fuel systems should be maintained to aviation quality standards. When other bunker fuels are loaded, as much JP-5 as possible should be consolidated into separate aviation quality storage. When JP-5 is mixed with other fuels or brought off-specification through contaminated systems the flexibility of using this fuel for aviation and the benefits of a universal fuel are lost. Most of the benefits of adopting JP-5 as the universal fuel at sea are not, however, achieved at the individual combatant level where other fuels would most often be mixed with JP-5. (Tosh, pp. 16-17)

4. Extended Fuel Filter Replacement Intervals

The inherent cleanliness of jet fuel will result in longer fuel filter replacement intervals than F-76. As discussed above, increased filter changes may be necessary when JP-5 is added to contaminated or deteriorated diesels.

5. Fuel Injectors and Fuel Pumps

Potential fuel lubricated injector and pump problems related to JP-5's lower viscosity and lubricity were discussed above. JP-5 is a cleaner fuel with higher thermal stability requirements, less water entrainment, etc. Using JP-5 will reduce diesel and turbine engine injection system nozzle fouling and fuel system deposits.

D. AIRCRAFT OPERATIONS

Replacing F-76 with JP-5 as the primary ships' bunker fuel will not affect aircraft operations as long as aircraft-quality cleanliness is maintained in tanks and fuel distribution systems used to support aircraft refueling.

E. BOILERS

The fireboxes in Navy ships' boilers, both D-type and pressure-fired, are tolerant of a wide spectrum of different distillate fuels. The design fuel for Navy pressure-fired boilers is JP-5. Using JP-5 in boilers should have no significant effects.

F. GAS TURBINE ENGINES

General Electric, the manufacturer of the LM2500 gas turbine engines used for Navy ships' propulsion, specifically approves JP-5 for use in all their turbine engines. Allison K01 series gas turbine engines, used for ships' service power generation, should also operate at least as well with JP-5 as F-76.

Due to JP-5's higher hydrogen content and greater thermal stability, using JP-5 should result in lower liner temperatures and longer combustor thermal-cycle life. Using JP-5 results in less soot production in the combustor and a reduction in the radiant heat transfer to the liner. Using JP-5 also reduces the potential for coking or fouling in atomizers that can cause fuel spray disruptions, hot streaks and damage to combustor liners.

G. DIESEL ENGINES

Engines operating with JP-5 will not run hotter. After switching back to diesel from JP-8, however, some diesel engines mechanically adjusted to optimally use JP-8 produce some over fueling at maximum throttle. Over fueling can cause excess smoke and, only under the most extreme conditions, over-temperature (JP-8 The Single Fuel Forward, p. 25). Since the heat density of JP-5 is higher than JP-8, optimizing adjustments would be smaller and problems with using F-76 or MGO in systems optimized for JP-5 would be less likely.

Theoretically, the lower cetane of JP-5 could reduce durability in diesel engines that are near design limit for power output or are particularly sensitive to injection timing

or ignition delay. In general, however, diesel engine durability should be similar or slightly improved when JP-5 is used instead of F-76. Lower rates of lubricant oxidation, fewer wear metals, less top ring wear, lower combustion chamber deposits, and slight reductions of injector deposits have resulted when engines operate with JP-8. (White Paper on JP-8, p. 6)

Theoretically, the lower cetane of JP-5 could make cold starting high-speed diesel engines more difficult. But, the lower viscosity, higher volatility, and lower waxing of JP-5 should make cold starting easier. The better storage stability of JP-5 will reduce fouling problems that can occur in launch boats and other systems that are not used very often. The lower viscosity of JP-5 has caused hot starting problems in a few diesel systems with inadequate rotary fuel pump designs. In general, JP-5 is inherently better both in significantly lower as well as higher temperatures than F-76 (Tosh, p. 2). Based on extensive prior use of JP-5 in diesel engines very few problems should be expected. (Tosh, pp. 20-21)

H. EMISSIONS AND SIGNATURE

Emissions and signature from using JP-5 should be lower because the lower viscosity, higher volatility, and lower cetane number of jet fuel results in better atomization, more premixed combustion, and slightly improved thermal efficiency compared with diesel. (JP-8 The Single Fuel Forward, p. 25)

I. SIMPLIFIED FUEL SYSTEM DESIGN

In order to maximize flexibility, ships must maintain the capability to use MGO and F-76 as substitute bunker fuels. Segregated bunker and aviation fuel tanks and systems will still be required on all ships. Simplified fuel system design for new combatants and tankers will not be possible.

J. FUEL OFFLOAD FOR MAINTENANCE

Ships need to offload fuel for some yard periods and maintenance. Since MGO and F-76 will be used as substitute bunker fuels and some JP-5 may be contaminated or off-specification for other reasons, the capability to offload fuels other than JP-5 must be maintained. Options for offload could include using barges to receive fuels other than on-specification JP-5, contracting to sell offloaded fuel, or transferring fuel to another ship's bunker tanks. At some DFSPs maintaining off-specification receipt capability would likely require maintaining segregated pipelines and tankage.

K. CONCLUSION

The Technology Demonstration of U.S. Army Ground Material Operating on Aviation Kerosene Fuel tested over 2,800 pieces of military equipment accumulating over 2,621,000 vehicle miles and over 71,000 operating hours in diesel and turbine driven generators. These tests compared performance using JP-8 and diesel fuel (DF-2). Results showed: (1) there was no statistically significant differences in average fuel consumption, (2) power loss was apparent in only a few power-limited engine systems, (3) there were

no catastrophic failures due to use of JP-8, (4) all fuel-related problems were resolved by technical consultation or were found to be similar to those experienced with diesel, (5) JP-8 is acceptable for use in diesel powered military systems. The study concluded that there were no cost penalties associated with the use of JP-8, but reduced maintenance of fuel systems, fewer replacements of fuel system components and extended periods between oil changes had potential to significantly reduce operational costs. (JP-8 The Single Fuel Forward, p. 136)

The results of using JP-5 in Navy systems should be similar. Potential technical and maintenance problems include:

(1) Reduced power and slower acceleration in some systems.

(2) Increased wear in some fuel lubricated pumps and injectors.

(3) Marginally increased fuel consumption and decreased range.

(4) Hot starting problems in some diesel engines with rotary fuel pumps.

(5) Initially increased fuel filter replacement after mixing JP-5 with diesel fuels.

Potential technical and maintenance benefits include:

(1) Reduced engine combustion-related component wear.

(2) Reduced nozzle fouling and deposit problems.

(3) Reduced potential for fuel system corrosion problems.

(4) Longer fuel filter replacement intervals.

(5) Reduced exhaust emissions and signature.

(6) Extended oil change and filter replacement intervals.

(7) Reduced low temperature operability problems due to fuel waxing.

(8) Reduced potential for microbiological growth problems in fuel tanks.

(9) Reduced water entrainment and emulsification problems in fuel tanks.

(10) Increased storage stability.

(11) Improved fuel and lubricant related cold starting.

Although it seems likely that the benefits discussed above will result in lower maintenance costs, actual savings are difficult to predict. Much of any savings will not be immediately apparent and even over time it may be difficult to directly correlate savings with the increased use of JP-5. Considering the higher cost of JP-5, maintenance savings alone likely do not provide enough justification to adopt JP-5 as the universal fuel at sea. However, reduced maintenance cost is one likely positive result of replacing F-76 with JP-5.

The following chapter discusses acquisition feasibility. That is, will refineries supply sufficient quantities of JP-5 to replace F-76 at reasonable costs?

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IV. AVAILABILITY AND ACQUISITION FEASIBILITY

A. INTRODUCTION

As discussed in chapter III, it is technically feasible to replace F-76 with JP-5. Technical feasibility, however, is not the only feasibility issue. The primary reasons JP-5 has not been adopted as the universal fuel at sea are the limited availability of JP-5 from refineries and the higher cost of JP-5, typically five cents more per gallon than F-76. These two problems are to some degree different facets of the same issue. It is the limited availability of JP-5 that results in higher prices and at higher prices availability would certainly increase.

Because DoD and allied navies are the only users of JP-5, worldwide demand and production is relatively very small. JP-5 accounts for only about 3 percent of U.S. jet fuel production (Task Group on Fuel Properties, p. 25). Refineries are designed and geared to produce large volumes of commercial products such as gasoline, diesel, and commercial jet fuel. They are reluctant to produce niche products such as JP-5 unless they obtain contracts for large volumes. This reluctance and other factors discussed below both limit the number of refineries interested in JP-5 production and increase the price. (Higgins, 22 September 1998)

JP-5 availability and sources are so limited, in fact, that DESC has difficulty purchasing enough JP-5 to meet routine peacetime aviation requirements. Although DESC has always managed to meet all requirements even during contingencies, it has

sometimes been necessary to use their leverage as the largest refined petroleum product customer in the world to pressure refineries and they have even been forced to impassion patriotism to gain adequate support. (Scheffs and Peschka, 16 March 2000)

If DESC has difficulty meeting routine peacetime aviation requirements alone, wouldn't it be impossible to increase JP-5 procurement to support bunker as well as aviation needs? Doubt about the answer to this question has prevented adoption of JP-5 as the universal fuel at sea since the issue was first examined in 1967 until today. This chapter addresses in some detail why JP-5 availability is limited, how this limited availability affects the price, how availability might be increased, and the fuel procurement costs of adopting JP-5 as the universal fuel at sea.

B. CAUSES OF LIMITED JP-5 AVAILABILITY

1. Limited Excess Refinery Capacity

Environmental regulations and the "not-in-my backyard" attitude of many communities has nearly, if not completely, stopped the construction of new refineries in the U.S. Additionally, persistently low profits have prompted domestic refiners to consolidate. Twenty percent of the U.S. refineries that were in operation in 1990 were closed by 1997 (U.S. Energy Information Administration website). At the same time, economic growth has increased commercial demand for petroleum products. Many U.S. refineries now operate at or near full capacity. For some refineries, responding to DESC

requirements means turning away existing customers. (Scheffs and Peschka, 16 March 2000)

2. Diminishing Importance of DoD as a Customer

DoD is the largest single purchaser of light refined petroleum products in the world. Historically, this position has enhanced the refinery response to DESC solicitations. Due to military downsizing, however, DESC fuel purchases are down 42.1 percent since FY 1988 (Task Group on Fuel Properties, p. 24). DoD's leverage as a most important customer is not what it was. Although DESC's procurement quantities are expected to remain nearly level in the future, worldwide commercial jet fuel demand is expected to grow 2.6 to 4.1% a year, further eroding any remaining refinery surge capacity and weakening DESC's buying power (Task Group on Fuel Properties, p. 76).

3. Refinery Logistics Constraints

The petroleum refining process is complex. Not just technically, but also logistically. Refineries generally do not store large quantities of either crude oil or finished products. Most refineries are just-in-time operations receiving crude oil when needed and delivering finished products matching specific customer orders for specification, quantity, and time of delivery. Production planning is more complex for petroleum refineries than for most other just-in-time manufacturers.

The specific chemical composition of each crude oil limits the types and relative quantities of products that can be produced and determines the processes required to

produce them. Producing more of one product often limits the quantity of another product a refinery can produce. For example, if a refinery produces more JP-5 they likely must reduce the output of other jet fuels that come from the same chemical fraction, or cut, of crude oil. At the same time, all parts of the crude must be used. Producing any product necessitates producing other perhaps less desirable products. When a fraction of crude is used to make gasoline, the remaining portion of the crude that is not suitable for making gasoline must be refined into something else. Refineries rely on computers and mathematical models to allocate crude oil components and refinery processes to determine how and how much of each product to produce each day, week, or month to match customer orders.

Ideally, a refinery has regular customers for all their products and maintains full production in a near constant balance that maximizes the total value of all products and minimizes changes in processes and outputs. Because the quantity of each product a refinery can produce is somewhat dependent upon all the other products they produce, refineries may be limited in their ability and desire to respond to new requirements, even urgent contingency requirements, from DESC.

4. Refinery Technical and Crude Oil Constraints

When a refinery separates and breaks down the chemical compounds in crude oils into useable products, the more restrictive the specifications for a product, the smaller the quantity or yield of that product that will be produced from each barrel of crude oil. JP-5

specifications are more demanding than other jet fuels and more demanding than any other bulk fuel most petroleum refineries produce.

The principal process by which all petroleum products are refined is distillation. Most refineries have an atmospheric crude distillation unit and a vacuum distillation unit, together known as the crude unit. The crude unit separates crude oil into cuts or streams. Figure 2 is a schematic diagram of a crude unit and table 4 identifies the typical streams produced from a crude unit. The volume of each stream produced primarily depends upon the properties of the crude oils processed. (Task Group on Fuel Properties, p. 14)

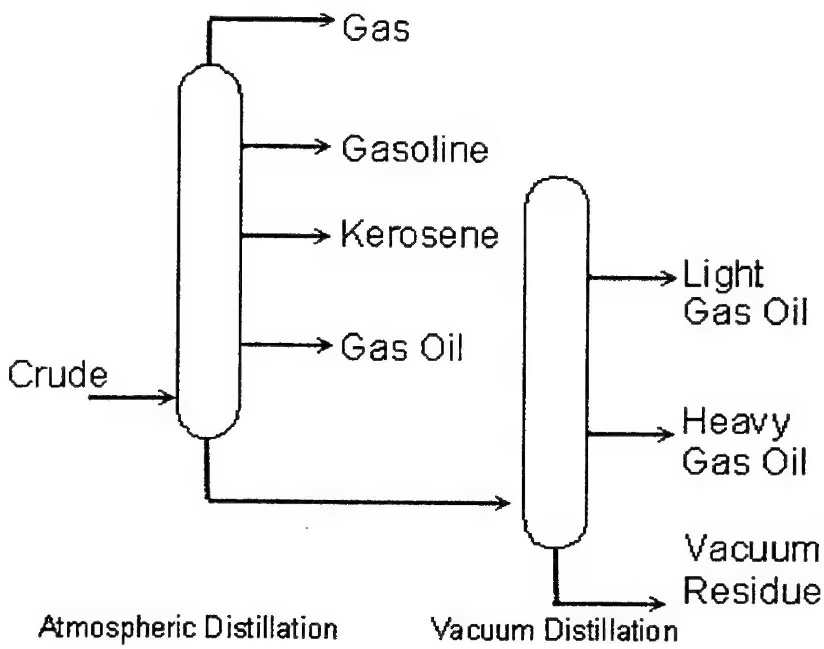

Figure 2. Schematic Diagram of a Crude Unit (from Task Group on Fuel Properties, p. 15)

Stream	Typical Boiling Range °F	Finished Products or Disposition
Gas	<100	Liquefied Petroleum Gas
Gasoline	100 – 400	Gasoline, Naphtha

Kerosene	300 – 500	Jet Fuel, No. 1 Diesel, No. 1 Fuel Oil
Gas Oil	400 – 650	Diesel, No. 2 Fuel Oil, Heating Oil, Cracker Feed
Vacuum Gas Oil	600 – 1000	Lube Oil, Cracker Feed
Residue	>1000	Asphalt, Coker Feed

Table 4. Typical Streams Produced from a Crude Unit (Task Group on Fuel Properties, p. 15)

A primary restriction in JP-5 production is that it must be made from straight distillate. Many refineries further refine the gas oil and vacuum gas oil streams through more complex processes such as cracking. Cracking processes break down larger heavier molecules into the smaller lighter molecules that make up the more valuable gasoline and kerosene streams. Because cracked fuels are less stable in long-term storage, JP-5 specifications require straight distillate fuel. Only the kerosene stream from the crude unit can be used to make JP-5.

But only a fraction the kerosene stream can be used to produce JP-5. The size of the JP-5 cut in the kerosene stream depends upon the particular chemical properties of the crude oil refined. Aromatics, smoke point, naphthalene, freeze point, and viscosity specifications constrain the low-end cut point. The 140° F flash point limits the high-end cut point.

Table 5 below lists the amount of 140° F flash point jet fuel that could be produced, relative to the quantity of 100° F flash point jet fuel that could be produced from 15 crude oil samples. (Task Group on Fuel Properties, p. 15)

Crude Sample	L	J	E	G	I	O	A	B	C	D	F	H	K	M	N
% Yield	60	52	47	38	18	11	1	0	0	0	0	0	0	0	0

Table 5. JET A1 yields at a 140° F minimum flash point specification relative to yields at a 100° F minimum flash point specification (Task Group on Fuel Properties, p. 81)

Table 5 shows that JP-5 cannot be produced at all from many crude oils and for all crude oils sampled the JP-5 yield was much lower than the commercial jet fuel or JP-8 yield. Refineries that receive crude oil that is unsuitable for JP-5 cannot produce it without changing their crude oil sources. Refineries that do not have flexibility in crude sources may not be able to produce JP-5 at all. (Task Group on Fuel Properties, p. 81)

5. The Impact of Environmental Regulations

The composition of gasoline and diesel fuels has been increasingly reformulated to reduce pollution. Some of these changes have reduced the potential JP-5 supply. In Europe, regulations have made diesel fuel more similar to kerosene and competitive with the JP-5 portion of the crude barrel. For some U.S. refineries producing JP-5 may make it more difficult to produce gasoline and diesel that complies with current state and federal environmental aromatics and distillation regulations (Task Group on Fuel Properties, p. 6 and p. 81).

6. Reluctance to Support DESC Annual Contracts

Some refineries are reluctant to bid on DESC contracts because they are awarded annually. Supporting DESC requirements may require investment to modify refinery configuration and output and refineries already operating near capacity may have to turn away current customers to supply DoD. Even if producing JP-5 for DESC would increase profits, some refineries have determined it is not worth bidding on a contract when they

risk losing it the following year. Small refineries are particularly risk averse and less likely to participate (Tosh, p. 12), but even large refineries may be reluctant to bid on annual contracts. Some refineries that have previously supplied JP-5 but lost subsequent contracts will no longer bid. (Scheffs and Peschka, 16 March 2000)

C. THE IMPACT OF LIMITED AVAILABILITY ON JP-5 PRICING

The inability to produce JP-5 from some crude oils and the relatively lower JP-5 yield from all crude oils may give the impression that JP-5 should be much more expensive than other jet fuels. This is, however, not true. The standard price of JP-5 in FY 2000 is only $0.01 per gallon more than the standard price of JP-8 and only $0.02 more per gallon than the standard price of commercial jet fuel. The lower quantity of JP-5 produced from a barrel crude does not mean that total refinery production decreases when JP-5 is manufactured. The portion of the crude that is not suitable for making JP-5 is still used to make other products.

However, the balance of products that a refinery's other customers demand will affect the interest a refinery has in producing JP-5 and the price that they will produce it for. In North America, demand for gasoline is higher than in other parts of the world and most refineries are configured to maximize gasoline production. Since gasoline uses a different cut of the crude, jet fuel production, including JP-5 production, can be complimentary to rather than competitive with gasoline production. In Europe and the rest of the world, where demand for diesel and gas oil is relatively higher, there is strong competition between jet fuel and gas oil and diesel for the kerosene distillate fraction of

the barrel. As a result, prices for jet fuel and JP-5 are higher overseas than in the U.S. (Task Group on Fuel Properties, p. 23)

Refineries that have been able to offer JP-5 at prices accepted by DESC are presumably those with crude sources and configurations most suitable for making JP-5 and with and other product outputs that complement rather than compete with JP-5 production. Since JP-5 production is only 3% of total jet fuel production, it isn't surprising that there are refineries that are well situated to make the quantities required. The fundamental question is, what would happen to the price of JP-5 if DESC purchased approximately twice as much JP-5 each year?

D. THE AFFECT OF INCREASED JP-5 PROCUREMENT ON PRICES

1. DESC Bulk Fuels Assessment

DESC refers to the ratio of the quantity offered by refineries to the quantity requested by their solicitation as coverage. For JP-5 coverage is typically only marginally above 100%. Often 100% coverage is only achieved through negotiation. In other words, there is little competition among refineries to supply JP-5 and to a large extent DESC must accept JP-5 from all the refineries that offer it. Referring to DESC's bidder selection process, an official from DESC Bulk Fuels said, "The last barrel always costs more than the first barrel." This implies that any increase in JP-5 procurement will increase the average price per gallon.

DESC Bulk Fuels officials believe that increasing procurement quantities would be difficult, prices would be at least marginally higher and in some areas and overseas prices could be significantly higher. However, if the conversion was phased over a period, perhaps as long as ten years, refineries would supply the required quantities of JP-5.

2. OPNAV N420 Assessment

An official from OPNAV N420, Head, Energy Plans and Policy Branch for the Deputy Chief of Naval Operations, Logistics, who participated in planning for and oversight of DoD's conversion to JP-8 ashore, believes DESC is overly pessimistic regarding the refinery industries ability to support changes in demand. He believes that if replacing F-76 with JP-5 is phased with sufficient lead-time for refineries to respond, the industry will provide the increased supply of JP-5 without significantly increasing prices.

3. Implications and Lessons Learned from the JP-8 Conversion

Although the conversion of DoD forces ashore to JP-8 was different from what a conversion to JP-5 as the universal fuel at sea would be, there are some similarities and lessons learned from the JP-8 conversion that could be valuable.

The JP-8 conversion was a much larger shift for the refinery industry than a JP-5 conversion would be. Consumption of JP-4 (the jet fuel used by DoD ashore prior to JP-8) before the conversion was about 15% of domestic jet fuel consumption. The follow-on conversion of ground vehicles, equipment and systems to JP-8 further increased the magnitude of the demand shift. Adopting JP-5 as the universal fuel at sea would increase

JP-5 consumption from only approximately three percent to less than six percent of domestic jet fuel production. The manufacture of JP-8 is easier than refining JP-5, however, so although the change was larger, in another respect it was easier for refineries to adapt. In addition, the JP-8 conversion occurred during a period of military downsizing, and reduced commercial demand.

Prior to the worldwide conversion of DoD ashore to JP-8, DoD anticipated availability problems and cost increases of five to ten cents per gallon over JP-4 (Task Group on Fuel Properties, p. 25). Similarly, today and during all previous studies of the issue, DESC and NAVPETOFF have predicted regional availability problems and higher prices if JP-5 is adopted as the universal fuel at sea (Scheffs and Peschka, 16 March 2000; and Higgins, 22 September 1998). But, the JP-8 conversion was successfully completed with actual JP-8 costs only two to three cents above JP-4 prices. Today the standard price of JP-4, for which there is very little demand or procurement, is $0.18 per gallon higher than the price of JP-8 (NAVPETOFF Notice 4265). (Task Group on Fuel Properties, pp. 25-26)

Perhaps the most important success factor in the JP-8 conversion was that it was carried out in phases over 16 years and the refinery industry had a lead-time of two to four years to prepare for each phase (Task Group on Fuel Properties, pp. 26).

4. Implications of the FAA Task Group on Fuel Properties Study

After the crash of Trans World Airlines flight 800 on 17 July 1996 was attributed to a fuel tank explosion, the Federal Aviation Administration (FAA) charged the Fuels

Properties Task Group 6/7 with assessing the feasibility of using a higher flash point fuel, similar to JP-5, in all commercial airlines. Task Group 6/7 included representatives from aircraft manufacturers, the petroleum industry, air carriers, and DoD. (Task Group on Fuel Properties, p. 1)

Converting the entire civil fleet to a high flash fuel would involve about twenty times the production quantity required to replace F-76 with JP-5. The conversion to JP-5 as a universal fuel at sea would only prompt those refineries best suited to refine JP-5 to consider producing it. The conversion of the entire civil fleet would require most refineries to make sizable investments in new systems and equipment to develop large volume high flash point jet fuel production capability. The higher quantities would also necessitate the use of unconventional refinery processing and increased use of cracked stocks. Since JP-5 is made only from straight distillate, the resulting fuel would not be JP-5. (Task Group on Fuel Properties, p. 14)

The Fuels Properties Task Group study included surveys of seventy-eight U.S. refiners representing practically 100% of U.S. jet fuel production capacity, 33 European refineries representing more than two thirds of European jet fuel production capacity, and 24 Japanese refineries representing 85% of Japanese jet fuel production capacity (Task Group on Fuel Properties, p. 73).

The Fuel Properties Task Group estimated, given a 150° F minimum flash point, it would require at least five years for the industry to meet demand and the cost of production would increase six to seven and one half cents per gallon in the U.S. and over twenty cents per gallon outside the U.S. (assuming a 7% return on investment). Of

course, the market rather than the cost of production would set the price paid by customers. (Task Group on Fuel Properties, p. 5)

Considering the slightly higher flash point and much higher quantities and refinery investments involved, the cost increases projected by the Fuel Properties Task Group should exceed the worst-case costs increase if JP-5 was adopted as the universal fuel at sea.

Refineries would be far less urgently motivated to respond to increased JP-5 requirements than to conversion of the entire civil fleet to high flash jet fuel. Considering the much less imposing adjustments required to increase JP-5 production, however, the period of at least five years required to meet the civil requirement, could be considered an indicator that the minimum phase in period for adopting JP-5 as the universal fuel at sea should be greater than five years.

E. IMPLEMENTATION STRATEGIES TO MAXIMIZE AVAILABILITY

Clearly, in order to increase JP-5 procurement without significant price increases DESC must find non-monetary methods to increase refinery interest in JP-5 solicitations.

1. Phased Implementation

As discussed above, the adoption of JP-5 as the universal fuel at sea would have to be phased in order to provide refineries lead-time to meet requirements. The phase-in period should probably be longer than five years and possibly as long as ten years.

In FY 1999, DESC sales of F-76 were approximately 750,318,000 gallons. In February 2000, DESC inventories of F-76 totaled approximately 310,968,000 gallons. The timing of F-76 replacement would not for the most part depend upon consumption of existing inventory.

DESC would have the option to phase F-76 replacement by DFSP or by region, or in any manner that would best eliminate shortages and minimize price increases.

2. Long-Term Agreements

As discussed above, some refineries are reluctant to participate in annual contracts. Other refineries likely reflect the risk of losing the next contract in their pricing. Since bulk petroleum contracts are indexed to allow prices to change with market prices, contracts do not lock prices in and neither DESC nor refineries risk that prices will become unfair or untenable over time. Since contracts do not specify an exact quantity that must be ordered, DESC retains some flexibility to order more or less as requirements change. Longer-term contracts or guaranteed renewal would ensure a secure supply for DESC and increase refinery participation at lower prices by providing the security of a long-term commitment.

F. FUEL COST ESTIMATE

The effect of increased JP-5 procurement on prices is uncertain and cannot be determined without actual contract negotiation. The typical standard price difference between JP-5 and F-76 over the last two decades has been fairly consistent at five cents

per gallon. The current price difference is three cents per gallon. Based on previous price behavior, DESC opinion, and the FAA study, it is possible to estimate that doubling JP-5 procurement will increase the average price of JP-5 between two and five cents per gallon.

Bunker fuel requirements are expected to remain level for the next few years at approximately 750 million gallons per year. A small drop in consumption, approximately 2.4 million gallons per year, will result from the decommissioning of the remaining two conventional aircraft carriers during the next decade.

Combining the demand for bunker and aviation fuel requirements will to some extent reduce variation in demand and permit a small reduction in DESC inventories while maintaining the same safety level. However, a cursory examination of demand variation at DFSP Puget Sound indicates there is a strong correlation between demand for aviation fuel and for bunker fuel, and combining variation probably would not significantly reduce safety stock.

Based on FY 1999 F-76 consumption (approximately 750 million gallons) and JP-5 consumption (approximately 647 million gallons) and price increases from zero to four cents per gallon, the fuel cost of replacing F-76 with JP-5 will be between 22.5 and 78.4 million dollars per year after complete implementation. The percentage increase in the Navy's total fuel budget, based on FY 1999 expenditures (approximately $1,547,300,000) would be between 2.42% and 3.88%. During the phase in period costs would be lower. Table 6 below shows the increased fuel cost of replacing all F-76 consumption with JP-5 at different potential price levels. (Defense Energy Support Center Fact Book, pp. 5-6)

JP-5 price increase (dollars)	.00	.01	.02	.03	.04
Standard price differential with F-76 (dollars)	.03	.04	.05	.06	.07
Total fuel cost increase (millions of dollars)	22.5	36.5	50.4	64.4	78.4
Percentage increase in total Navy fuel costs	1.5%	2.4%	3.3%	4.2%	5.1%

Table 6. The Annual Cost of Replacing F-76 With JP-5

To put this potential fuel cost increase in some perspective, consider the market volatility of fuel prices. The market prices of both fuels continuously change. A seven-cent increase in the market price of fuels, which must be considered fairly routine and which was certainly exceeded in FY 2000, would have the a larger effect than replacing F-76 with JP-5 at a price that is seven cents higher per gallon than F-76. This does not imply that the potential cost increases are not real or significant, but that the magnitude of the cost increase is not overwhelming.

These estimates also only consider the increased cost of fuel. Some of this increased fuel cost may be offset by lower maintenance, contract administration and transportation costs.

G. CONCLUSION

JP-5 availability is limited; replacing F-76 with JP-5 will be feasible if phased over a period of five to ten years. By using longer-term contracts or guaranteed renewal agreements with refiners, the potential for shortages and price increases can be minimized.

JP-5 costs more than F-76 and replacing F-76 with JP-5 will increase fuel costs. Although the amount of the cost increase is uncertain, after full implementation it will

probably be between 22.5 and 78.4 million dollars per year and between 1.5 and 5.1% of FY 1999 Navy fuel expenditures.

Some of the increased fuel cost may be offset by reduced maintenance costs, contract administration, and transportation costs.

Chapters III and IV of this research determined that adopting JP-5 as the universal fuel at sea is feasible, but it would increase costs. The remaining question for this research is: do the benefits of adopting JP-5 as the universal fuel at sea exceed the costs? Unfortunately, this question cannot be answered with simple numbers. It is impossible to put a price on the improved readiness and mission capability. But, the readiness benefits are significant. As will be discussed in Chapter V, although the limited availability of JP-5 is the major obstacle to adopting it as the universal fuel at sea, limited availability also makes adopting JP-5 as the universal fuel at sea necessary.

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V. OPERATIONAL AND LOGISTICAL BENEFITS

A. INTRODUCTION

The previous chapters established that it is feasible to adopt JP-5 as the universal fuel at sea, but it would be challenging to develop adequate refinery support for the increased quantities and fuel costs would increase between 22.8 and 78.4 million dollars. Although maintenance costs would be reduced by use of JP-5 as a bunker fuel, it is difficult to determine the cost savings and in any case they almost certainly will not justify replacing F-76. Contracting costs, inventory costs and administration costs might also be reduced by replacing two fuels with a single fuel, but again these offsetting savings will not justify replacing F-76. Because ships will still use MGO as a substitute fuel, segregated bunker tanks and systems will still be required. Simplified fuel system design for new ships will not be possible.

Replacing two fuels stored in DFSPs with a single fuel may reduce variation and may allow reduced inventories while maintaining the same safety level, however, any potential reduction would be small and would only provide a one-time savings. Duplicate systems used to support two fuels at DFSPs might be abandoned saving upkeep costs or they might be maintained increasing redundancy and readiness. Because ships will still use MGO and will still need to offload for yard periods and some maintenance, however, some segregated tankage and pipelines would still be required in some locations. Adopting JP-5 as the universal fuel at sea probably will not save money.

The previous paragraphs summarized not only the first three chapters of this research, but also the results of all previous studies of the potential universal fuel at sea. There are, however, other benefits to consider. Those benefits are addressed in this chapter.

In any contingency there are risks. The Navy depends upon delivery of adequate fuel supplies to the area of operation to maintain operations on station. This support requires both an adequate supply of fuel and adequate transportation to deliver that fuel to forces at sea. The risks to both the Navy's fuel supply and to the capability to move that fuel to forces at sea are greater today than a decade ago. Without corrective action the risks of petroleum logistics failure will be greater still in the future. The following chapter identifies the sources of the Navy's petroleum logistics risks and how adopting JP-5 will reduce those risks.

B. FUEL SUPPLY RISKS

Many refineries now operate at or near full capacity and economic growth continues to increase commercial demand for petroleum products (Scheffs and Peschka, 16 March 2000). At the same time, DoD is becoming a less important customer as fuel purchases shrink as a percentage of refinery output. Meeting all DoD fuel requirements during contingencies will be increasingly challenging in the future.

This challenge is more critical and more significant for JP-5 than for other DoD bulk fuels. If JP-8 supplies are insufficient forces ashore will substitute JET A1; if ships' bunker fuel supplies are insufficient, ships will substitute MGO for propulsion; but if JP-5

supplies are inadequate the Navy will either be forced to limit flying or to fly unsafely using JET A1 or JP-8. Almost any refinery can produce both JET A1 and MGO and even at the height of a contingency, DoD requirements for those commercial fuels are only a small fraction of worldwide consumption. Not every refinery can make JP-5 and it is a unique military fuel without any equivalent or substitute, commercial or military.

DESC maintains war reserves at DFSPs around the world, but these reserves are only large enough to meet the deployment and combat operation requirements of a contingency in the geographic area until resupply can be obtained from a secure source (DDOD 3110.6). War reserves will not sustain operations.

Although DESC has never had a mission failure, that organization has been challenged meeting past contingency requirements. Immediately prior to Iraqi invasion, DESC was contracting 100% of the JP-5 supply from Kuwait. When that source was lost, only the patriotic impulse of Leon Hess, founder of Amerada Hess Oil, ensured an adequate supply of JP-5 for the Gulf War. (Scheffs and Peschka, 16 March 2000)

JP-5 supply is the Achilles' heel of DoD petroleum logistics. Without corrective action, there is real risk that DESC will not be able to procure the JP-5 required to support naval aviation operations during a major contingency.

C. FUEL TRANSPORTATION RISKS

Recognizing that oilers and tankers are high value assets that may be targeted by the enemy, the Navy has developed a robust system that can absorb losses. The first logistical safeguard is maintaining high fuel levels throughout the system. Ships routinely

replenish when fuel levels drop to approximately 85% of capacity. This ensures that if the battle group station ship is lost they will have sufficient fuel onboard to maintain operations until the next shuttle oiler arrives. Station ship CONSOLS are scheduled frequently enough to ensure that if a shuttle oiler is lost enroute the station ship's stocks will maintain the battle group until another shuttle ship will arrive.

The second logistical safeguard is the flexibility of petroleum transportation assets. All types of Combat Logistics Force ships, not just oilers, are capable of UNREP. Even carriers are capable of escort UNREP. Shuttle ships can serve as station ships. MSC tankers can serve as shuttle ships and are also capable of UNREP. Commercial tankers can CONSOL or even provide UNREP if a modular delivery station is installed.

Nevertheless, DoD's capability to support all petroleum movement requirements in the event of two nearly simultaneous major regional conflicts is questionable and the risk of failure is increasing. In almost any contingency, fuel transportation requirements exceed the capability of government owned tankers. Augmenting MSC capabilities with commercial tankers during contingencies is rational, economical and intended; however, the number of available militarily useful commercial tankers might be insufficient.

1. Aging Sacramento Class Fast Combat Support Ships

The U.S. Navy currently has eight fast combat support ships (AOEs) and thirteen MSC Kaiser Class oilers (T-AOs) to provide tactical and operational petroleum support (i.e., intratheater fuel movement, CONSOL and UNREP). AOEs are assigned as station ships; an organic element of each carrier battle group intended to remain with the battle

group to maintain on-hand resupply stocks and flexible UNREP timing. The Navy has more battle groups than AOEs. When an AOE is not available for a carrier battle group, both a TAO and an ammunition ship (AE) are assigned as station ships, the pair somewhat equivalent to an AOE. TAOs also serve as shuttle oilers delivering fuel from the nearest DFSP for CONSOL with station ships and UNREP to combatants operating without station ships.

Four of the AOEs are Sacramento class with an average age of 32 years and a planned service life of 35 years. As these ships age, their reliability decreases and maintenance time and expense increase. To augment the insufficient number of station ships and to replace the aging Sacramento class, a new class of Combat Logistics Force (CLF) vessels, the T-ADC(X), will begin delivery in fiscal year 2004 with a total of 12 ships scheduled for delivery by the end of fiscal year 2006. The T-ADC(X) only carries 18,000 barrels of fuel (10,500 barrels of F-76, and 7,500 barrels of JP-5) compared to 177,000 barrels for the Sacramento class. The T-ADC(X) will be capable of replenishing ammunition and stores, but clearly it is not an oiler. If a T-ADC(X) is assigned to a battle group, either a T-AO must also be assigned as a station oiler or the security and flexibility provided by a station oiler will be lost. (Keane, p. 19)

Using TAOs as station ships is effective during peacetime, but they have a competing mission to serve as the shuttle ships that resupply station ships. After the four Sacramento Class station ships are decommissioned, in two nearly simultaneous major regional contingencies as many as six of the thirteen TAOs might be used as station ships, leaving only seven TAOs to perform the shuttle mission. During two near simultaneous

major regional contingencies, or even during a single large contingency when the transit time between the area of operations and the nearest DFSP is longer than a few days, the shuttle capacity of the TAOs could be inadequate. If the number of TAOs was insufficient, one or more station ships would need to detach from their battle groups to augment shuttle lift.

When a battle group is without a station ship, the unexpected loss of a shuttle could result in insufficient fuel to maintain the desired operational tempo. In addition, without a station ship the battle group commander loses control over when underway replenishment occurs. Underway replenishment can only be scheduled when the tactical situation, operations and weather permits. Without a station ship, the battle group commander is forced to schedule underway replenishment whenever a shuttle oiler is available to provide it. Providing UNREP instead of CONSOL also reduces shuttle efficiency. The time a shuttle oiler spends on station with the group reduces total shuttle lift capability.

The AOEs and TAOs providing tactical and operational petroleum transportation will be heavily tasked in any major contingency and requirements may exceed their capabilities. MSC tankers and even commercial tankers can also provide shuttle, CONSOL or even UNREP, but as discussed below, these assets may also be heavily tasked.

2. Declining Number of Militarily Useful Tankers

Over six thousand merchant tankers ply the seas, but most of these tankers are not militarily useful because of their size. To be useful for DoD, tankers must be large enough to carry a practical quantity of fuel, but not so large that they exceed the terminal space, draft constraints and capacity to receive fuel at the off-load terminal. Generally, only clean-product tankers sized between 6,000 and 80,000 deadweight tons are militarily useful. Handy size tankers, between 6,000 and 35,000 deadweight tons, and carrying between 48,000 and 280,000 barrels are most useful. Their advantages are their ability to enter most ports, short time to clean if necessary and flexibility to carry different types of fuel. (JP 4-01.02, p. IV-6; Keane, pp. 11-14)

The International Convention for the Prevention of Pollution from Ships, 1973, adopted by the International Maritime Organization, an agency of the United Nations, requires all new tankers to be constructed with double hulls or equivalent and all older tankers to be retrofitted by thirty years after their date of delivery. After the Exxon Valdez oil spill, Congress passed the Oil Pollution Act of 1990 (OPA 90), which requires all tankers operating in U.S. waters to have double hulls by 2015. Retrofitting old tankers or purchasing new double hull tankers is expensive and many tankers are taken out of service without replacement. Those that are replaced are often replaced with more economical oceangoing barges or larger supertankers. Barges are not well suited for the long-haul requirements of strategic sealift. Supertankers are generally too large to be

militarily useful, and cleaning a crude tanker before it can carry fuel takes about two weeks and is very expensive (JP 4-01.02, p. IV-6). (Keane, p. 27)

3. Declining Number of U.S. Flagged Tankers

Chartering U.S. tankers is preferred to using foreign vessels. The current U.S. flagged clean product tanker fleet consists of only 62 active vessels (including the tankers under MSC charter). The U.S. tanker fleet is small because operating U.S. flagged ships is more expensive than operating foreign flagged ships. As a result, U.S. flag tankers are used exclusively for domestic transportation that is legally protected from foreign competitors. (Keane, pp. 24-26)

Due to declining demand and the effects of OPA 90, the U.S. tanker fleet has been shrinking rapidly and is expected to continue to decline. Between 1995 and 1997, barges replaced approximately 12% of domestic clean product tankers (Keane, p. 27). During the 1990s, 50 clean product tankers were removed from the domestic fleet and only ten new tankers were added, a decline of nearly 40% (Keane, p. 25).

One source of the decreased demand has been military downsizing. In 1990 MSC term chartered 21 tankers, today only five tankers are under term charter. DESC spot charters (single point-to-point lifts) are also down 50% since 1990. Another cause for decreased domestic tanker demand is improved oil company efficiency achieved through mergers and product cargo exchanges. Consolidating resources through mergers and agreements with competitors has allowed oil companies to supply products from refineries closer to their customers. Today, the supply of domestic clean product tankers exceeds

demand and 15 of the 62 active tankers are used to transport grain instead of fuel. (Keane, pp. 26-29)

Although domestic clean product tanker supply exceeds demand today, due to OPA 90 phase-out requirements, by 2005 demand is expected to exceed supply. To support domestic fuel transportation needs, approximately 45 tankers are required. The domestic fleet is expected to shrink to only 37 clean product tankers by 2008. At that time, the number of domestic clean product tankers may be insufficient to meet commercial needs critical to the economy. U.S. flagged tankers probably will not be available at all to support contingency requirements and DoD will need to rely on RRF, NDRF and foreign flagged vessels. (Keane, pp. 25-29)

4. Aging Ready Reserve Force (RRF) and National Defense Reserve Fleet (NDRF) Ships and Declining Merchant Marine Manning

If the number of available merchant tankers is insufficient, MARAD will activate the Ready Reserve Force (RRF) and National Defense Reserve Fleet (NDRF) tankers. All of the NDRF and RRF ships are common-user assets that will support other DoD forces as well as the Navy. Eight of the ten RRF tankers specialty tankers that are not designed or intended to support Navy fuel requirements. Most of the twenty RRF and NDRF tankers were built in the 1950's and 1960's, the newest was constructed in 1971 and the oldest in 1945. As these ships age they will become increasingly unreliable and no new acquisitions are funded. Another problem with activating the RRF and NDRF is manning. The number of U.S. merchant marine tanker billets has declined from 6,180 in 1990 to

3,840 in 1999 (Keane, p. 29). As the number of tanker billets declines, the number of mariners qualified to man the RRF and NDRF ships also declines. NDRF tankers were not activated for Desert Storm. The capability of the RRF and NDRF to sustain contingency support primarily intended to support forces ashore and increasingly uncertain. (Keane, pp. 23 and 59)

5. Dependence on Foreign Flagged Tankers

Since the U.S. tanker industry is approaching extremis and RRF and NDRF support of Naval fuel requirements is extremely limited, the Navy will depend upon foreign flagged shipping to support strategic petroleum lift requirements during contingencies. Using foreign flagged vessels is not an unacceptable risk or a crisis. More than 50 U.S. owned tankers that fly foreign flags are considered effectively U.S. controlled and could be requisitioned in a national emergency declared by the President (Keane, pp. 31-32). Fifty-nine tankers flagged in NATO countries and 12 tankers flagged in South Korea are also available to meet emergency DoD requirements under government agreements (Keane, pp. 33-34). Foreign flagged vessels were used during the Gulf War and are routinely used by DoD in peacetime.

In a contingency with less international consensus than the Gulf War, however, the availability of foreign flagged tankers to support DoD might be restricted by their respective national governments. The availability of militarily useful tankers is declining worldwide, merchant tankers also have commercial commitments to support and the market supply of ships does not expand when contingencies occur. Although MSC should

be able to charter the tankers required to support contingency needs, there is some risk that an adequate number of tankers will not be available.

6. Delayed Availability of Tanker Assets

Delayed availability of tankers could also present problems early in a contingency. The minimum delay for any tanker would be the transit time to the theater of operations. Many chartered vessels would first need to transit, offload their current cargo, transit again and load DoD cargo before they could start toward the theater. RRF ship activation takes only from four to thirty days, but preparing some NDRF ships to leave port would take as long as 135 days. (Keane, p. 35)

7. Summary of Availability vs. Requirements

During Desert Shield and Desert Storm, MSC used 69 tankers: 4 RRF, 38 U.S. flagged, and 27 foreign flagged vessels (Keane, p. 36). During the gulf war the facilities and infrastructure of neighboring countries were very good and refinery sources for most fuels were reasonably close to the theater (Keane, p. 5). In future conflicts, DoD may not be so fortunate and tanker requirements could be greater. During two nearly simultaneous major regional contingencies, requirements could be more than double those of the Gulf War.

At the beginning of the Gulf War, MSC already had 25 government owned or contracted tankers transporting fuel, at the beginning of any future conflict that number would be probably be less than ten (Keane, p. 36). The number of U.S. flagged tankers

available would likely be less than a third of the number used in the Gulf War. In the next decade, the availability of U.S. flagged tankers that are not already under long-term charter to MSC may approach zero. RRF and NDRF vessels are aging and have potential manning problems. Worldwide the number of militarily useful tankers has declined significantly since the Gulf War. Over 100 effectively U.S. controlled, NATO and South Korean tankers are theoretically available to DoD during contingencies, but the vast majority of these ships are actively engaged in commerce and using them all would reek havoc on the world economy. Tankers flagged in other nations could also be chartered, but nations that do not support our goals might prohibit the use of their ships.

All this does not necessarily mean that a sufficient number of tankers could not be acquired, but it does mean that there is risk that that would not be acquired and that proposals that reduce tanker requirements must be considered.

D. REDUCING RISK WITH THE UNIVERSAL FUEL AT SEA

Adopting JP-5 as the universal fuel at sea would substantially reduce both fuel supply risks and fuel transportation risks, improve readiness, and enhance the Navy's capability to sustain major contingency operations.

The universal fuel at sea would replace F-76 war reserves and peacetime operating stocks stored in DFSPs around the world with more flexible, critical and difficult to obtain JP-5. In February 2000, DESC worldwide inventories of F-76 totaled approximately 310,968,000 gallons and JP-5 inventories totaled approximately 578,760,000 gallons

(DESC Website). Replacing F-76 inventories with JP-5 would increase JP-5 inventories by approximately 50%.

As an approved alternative to both F-76 and JP-8, JP-5 is the only fuel that can be used by all services for all bulk fuel requirements. JP-5 stocks provide DoD more flexibility and increase readiness to meet all contingency needs. Even the relatively small JP-5 requirements of the recent Kosovo operations were initially difficult for DESC to support. Although DESC personnel believe they certainly would have found a solution, if two aircraft carriers had been needed for the operations, they acknowledge it would have been very difficulty to provide timely resupply of JP-5 (Scheffs and Peschka, 16 March 2000). As a result, DESC intends to convert some of the JP-8 war reserves in the Mediterranean to JP-5 (Scheffs and Peschka, 16 March 2000). These reserves could still be used to support Air Force, Army and Marine requirements that would normally be supported with JP-8. Ideally all war reserves, including those currently held as JP-8, would be held as JP-5.

Larger JP-5 inventories would extend the time available for DESC to contract for and deliver JP-5 to meet increased contingency requirements. Since other bulk fuels used by DoD, including MGO and F-76, are more likely than JP-5 to available through host nation support, increased JP-5 inventories could also reduce the needed quantity and urgency of early tanker lifts.

The availability of JP-5 refinery production capacity sufficient to sustain Naval forces during a major contingency is uncertain. By adopting JP-5 as the universal fuel at sea, the routine peacetime production of JP-5 will be approximately doubled and most

likely more refineries would be contracted by DESC to provide JP-5. Starting from a larger supplier base and a larger base quantity, increased JP-5 requirements during a smaller contingency might be more incremental than substantial. During a major contingency, doubling the JP-5 production base would also improve the capability to sustain operations. Although adopting JP-5 as the universal fuel at sea would double peacetime consumption as well as supply, if the supply of JP-5 was inadequate to support both aviation and bunker requirements during a contingency, DESC could contract with local refineries for F-76 or MGO to support bunker requirements. The JP-5 supply, then initially twice the current size, could be reserved for aviation needs. The risk of inadequate refinery support for JP-5 requirements would be substantially reduced. By attempting to procure substitute bunker fuels as near as possible to the area of operations, tanker requirements could also be reduced.

E. ADDITIONAL BENEFITS WHEN ONLY JP-5 IS USED

Using a single fuel increases efficiency through simplified logistics, reduced variation and greater predictability of demand. Replenishment at each level of the supply chain cannot be planned to support the mean expected consumption. Such support would be inadequate 50% of the time. Replenishment must be planned to meet the highest reasonably expected demand. It is a statistical certainty that using a single fuel would reduce variation in demand. The total quantity of fuel required would be more predictable and the combined highest reasonably expected demand for both aviation and bunker support would be lower than each requirement determined separately. In other words, a

lower quantity of a single fuel that supports all systems provides the same readiness and safety level as higher quantities of two fuels that each support different systems. In addition, increased predictability would enhance the logisticians' capability to push fuel to the theater rather than waiting for submitted requirements.

Using a single fuel increases the days-of-supply endurance of the fleet. With two fuels, endurance is limited by whichever fuel will be depleted first. A ship loaded with only JP-5 has greater endurance than a ship loaded with both F-76 and JP-5. For example, a ship might have plenty of F-76, but be low on JP-5 and need an UNREP to support aviation operations. The same ship with the same total amount of fuel, but only JP-5, might have adequate fuel to safely sustain both propulsion and aviation for a few more days. Increased endurance reduces the risk to operations from the unexpected loss of a station ship. With a single fuel UNREPs can be less frequent. Less frequent but higher quantity UNREPs allow greater freedom to schedule around threats, operations and weather and less total time actually alongside.

The same principle also applies to whole battle groups. CONSOL of battle group oilers must be scheduled based on expected consumption of the fuel that will be depleted first. Using a single fuel increases the endurance of the entire battle group and reduces the risk to operations from the unexpected loss of a shuttle ship. Less frequent but higher quantity CONSOLs would increase shuttle oiler efficiency.

In addition, fewer tankers and oilers would be wasted moving fuel that is not needed. Since shuttle oilers would never deplete the onboard inventory of one fuel and still have excess of another fuel onboard, all fuel onboard could be transferred during

every shuttle. Flexibility would be improved, planning would be easier and less communication would be necessary. Fewer shuttle oilers and fewer escorts would be required.

The benefits of a single fuel would be lost whenever MGO or F-76 was used as substitute bunker fuel; however, the benefits of obtaining bunker fuel locally would often exceed the benefits of using a single fuel. Using substitute bunker fuels will allow reserving JP-5 to support the aviation requirements for which it is absolutely necessary and obtaining bunker fuel locally would also reduce transportation requirements.

E. LOADING MGO ABOARD OILERS

If MGO was designated the alternative bunker fuel, procurement of adequate quantities at a reasonable distance would be much easier and nearly assured. MGO is an acceptable bunker fuel, however, accepting MGO as the primary bunker fuel during a contingency would require loading MGO as oiler cargo. Currently, loading MGO as oiler cargo is not accepted.

The most significant difference between MGO and F-76 is the better storage stability of F-76, but during a contingency high inventory turnover would eliminate long-term storage. The real concern with loading MGO on oilers is the possibility of loading bad fuel onboard an oiler and then replenishing one or more battle groups with that bad fuel. While MGO that meets DESC purchase requirements would not cause problems, much of the MGO on the commercial market today does not meet those requirements.

Loading oilers with MGO during a contingency could not and would not be handled in the same manner as ships' bunkering. The higher quantities involved would necessitate new contracting and close coordination between DESC and suppliers. Most suppliers would be refineries, not vendors. Much more rigorous quality assurance and thorough testing would be necessary before loading. In most cases, the expense and challenge of providing adequate quality assurance for loading MGO on oilers would be much less than the expense and challenge of attempting to procure military specification F-76.

G. CONCLUSION

The Navy faces considerable risks that during a major contingency the availability of JP-5 and the availability of tankers and oilers to move fuel to the theater of operations would be inadequate. These risks are increasing. Adopting JP-5 as the universal fuel at sea would double the peacetime base refinery production of JP-5 and increase DoD inventories of JP-5 by 50%. Combined with accepting MGO as the primary bunker fuel whenever advantageous, adopting JP-5 as the universal fuel at sea would substantially increase the availability of JP-5 to support aviation requirements. It could also reduce the number of tankers and oilers required to support operations. Adopting JP-5 as the universal fuel at sea would enhance readiness and improve the sustainability of U.S. Navy forces.

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VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

To maximize simplicity, flexibility and interoperability, Joint Publication 4-03, *Joint Bulk Petroleum Doctrine* states, "Department of Defense components should minimize the number of bulk petroleum products that must be stocked and distributed." (JP 4-03, pp. I-1 – I-2) The current naval aviation fuel, JP-5, could also be used as the primary fuel for shipboard systems (bunker fuel). "All shipboard systems, including boilers, turbine engines and diesel engines should continue to operate satisfactorily, and in some instances, with increased efficiency with JP-5." (Tosh, p. ii)

However, the Navy continues to use two fuels because JP-5 is more expensive than F-76, the current primary bunker fuel, and the availability of JP-5 from refineries is limited. The Navy faces a considerable risk that in a major contingency the supply of JP-5 will be inadequate to support the aviation mission. This risk to the JP-5 supply is also increasing. Commercial demand for fuel is rising due to economic growth, but the number of U.S. refineries is stagnant. Many U.S. refineries now operate at or near capacity and have little desire or even ability to increase JP-5 production to respond to DoD's contingency requirements. Due to military downsizing, DoD's leverage as a most important customer is not what it was. For technical reasons, many refineries cannot produce JP-5 even if they want to support DoD.

For other DoD bulk fuels, JP-8 and F-76, there are commercial substitutes available in large quantities around the world. JP-5, however, is a unique military fuel for which there are no substitutes, military or commercial. If the supply of JP-5 was insufficient during a contingency, the Navy would be forced to either reduce the operational tempo or fly using other jet fuels that are unsafe for shipboard use. These are not acceptable alternatives. JP-5 supply is the Achilles' heel of DoD petroleum logistics.

The conclusion of this research is that JP-5 should be adopted as the universal fuel at sea, that is, the only fuel stored and distributed by DoD for shipboard use. The principal justification is not maximizing simplicity, flexibility or interoperability, or to lower maintenance costs, or reduce infrastructure, although those benefits can be expected. Adopting JP-5 as the universal fuel at sea is necessary in order to expand the JP-5 production industrial base to ensure an adequate supply of JP-5 during future contingencies.

Adopting JP-5 as the universal fuel at sea would double the routine peacetime refinery production of JP-5 and increase DoD inventories of JP-5 by 50%. Although routine peacetime consumption would be doubled along with the supply, during contingencies when the supply of JP-5 is inadequate, substitute commercial bunker fuels could be used and the then larger JP-5 supply reserved for aviation requirements.

Increasing the refinery supply of JP-5 to meet the needs of a universal fuel at sea would be challenging and could only be accomplished over an extended period, possibly as long as ten years. The cost of replacing F-76 with JP-5 is difficult to determine, but fuel costs would probably increase between 22.5 and 78.4 million dollars per year. The

increased fuel cost would be partially offset by reduced maintenance, administration, infrastructure and transportation costs.

B. RECOMMENDATIONS

OPNAV 420, Energy Plans and Policy Branch for Deputy Chief of Naval Operations, Logistics has sponsored a study that will examine the costs and benefits of replacing F-76 with JP-5. Phase 1 of the OPNAV 420 study, scheduled for completion near the end of calendar year 2000, will examine in detail whether refineries can provide JP-5 in the quantities and places required. Phase 1 will also include a preliminary cost estimate. Phase 2 of the OPNAV study will examine issues related to engine operation and maintenance when JP-5 is used full-time. Phase 2 will also include the final cost estimate. The OPNAV 420 study will the review the analysis of this research, and will reexamine and refine the recommendations below.

Recommendation: Recommend DoD and the Navy adopt JP-5 as the universal fuel at sea, replacing F-76 as the primary fuel used for shipboard systems and as the bunker fuel stored in DFSPs as war reserves and peacetime operating stocks. Adoption of JP-5 as the universal fuel at sea would not prohibit or discourage the use of F-76 and MGO as alternative bunker fuels or alter the use of fuel exchange agreements, bunker contracts, or open purchase to obtain fuel.

Recommendation: Recommend the N420 single fuel study research and propose a timetable and methodology (by region or by DFSP for example) for phasing out F-76 that will provide sufficient lead-time for DESC and refineries to increase the supply of JP-5 and minimize price increases and availability problems.

Recommendation: Regardless of the final decision to adopt or not to adopt JP-5 as the universal fuel at sea, recommend DESC develop long-term or guaranteed renewal contracts for bulk fuel. Some fuel suppliers do not do business with DoD because DESC bulk fuel contracts are awarded annually. This problem is particularly acute for JP-5 procurement. To produce JP-5, some refineries require investment that cannot be justified by a single year contract. Long-term commitment by DESC will increase refinery participation and reduce the cost of bulk fuels.

Recommendation: Regardless of the final decision to adopt or not to adopt JP-5 as the universal fuel at sea, recommend DESC develop policy and procedures for bulk purchase of and tanker or oiler loading of MGO. In a major contingency there is the possibility that the supply of F-76 would be inadequate or that tanker assets to transport F-76 from a more distant refinery where it can be procured would not be available. Purchasing MGO near the area of operations may be necessary. Establishing bulk MGO purchase procedures, including quality assurance procedures, in advance will prepare DESC for this potential contingency requirement.

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